JET PROPULSION

Journal of the

AMERICAN ROCKET SOCIETY

Rocketry . . . . Jet Propulsion Sciences . . . . Astronautics

VOLUME 25 NOVEMBER 1955 NUMBER 11

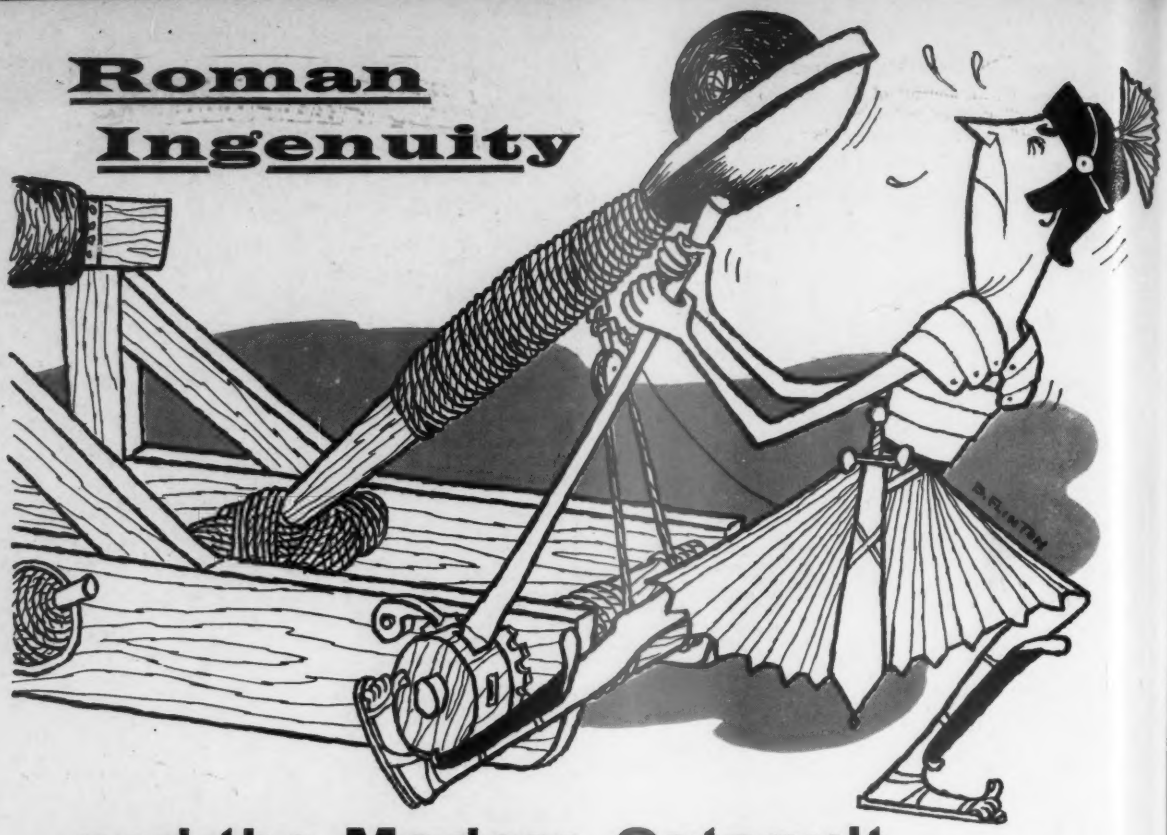
25th Anniversary Issue

Ramjet-propelled TALOS missile (left), launched by solid propellant booster at NOTS, China Lake, Calif., typifies modern achievements in jet propulsion. (See article by W. H. Avery, p. 604.)

rial Comments . . . . . R. W. Porter, M. Summerfield, I. Glassman 584
First Quarter Century of the American Rocket Society . . . . . G. Edward Pendray 586
ty-Five Years of Rocket Development . . . . . Howard S. Seifert 594
ty-Five Years of Ramjet Development . . . . . W. H. Avery 604
Problems, and Status of Guided Missiles . . . . . George P. Sutton 615
ty-Five Years of Progress Toward Space Flight . . . . . Milton W. Rosen 623
tional Cooperation in Rocketry and Astronautics . . . . . Andrew G. Haley 627
ed ASA Letter Symbols for Rocket Propulsion . . . . . R. Youngquist and J. P. Layton 634

Jet Propulsion News . . . 646
Space Flight Notes . . . 650
ARS News . . . 651
New Patents . . . 659
Book Reviews . . . 662
Technical Literature Digest . . . 669

Roman Ingenuity



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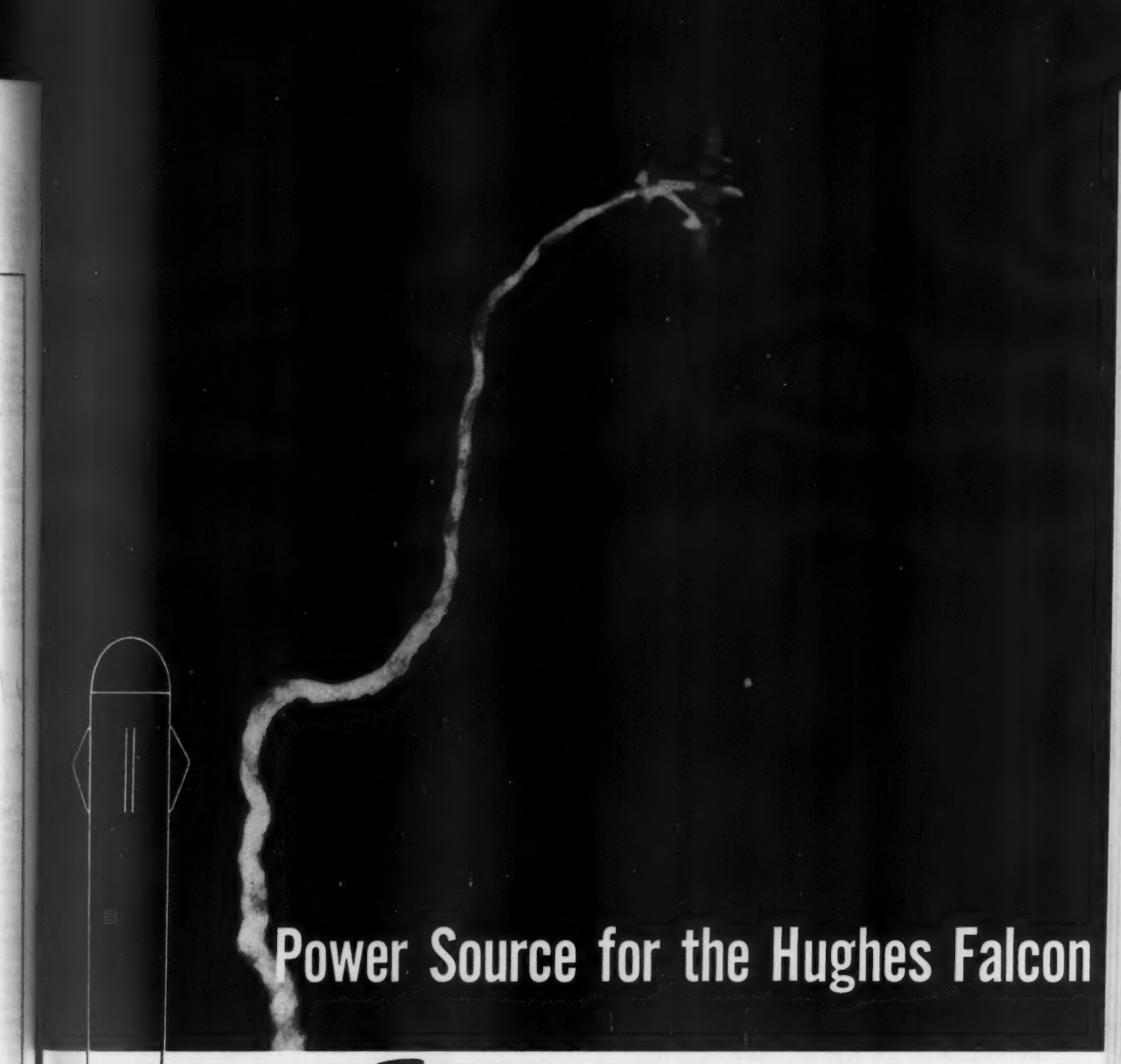
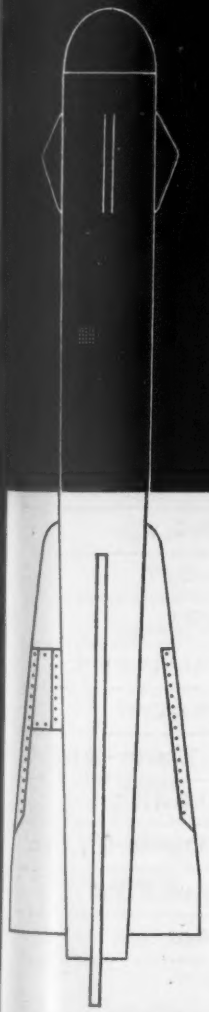


Power Source for the Hughes Falcon



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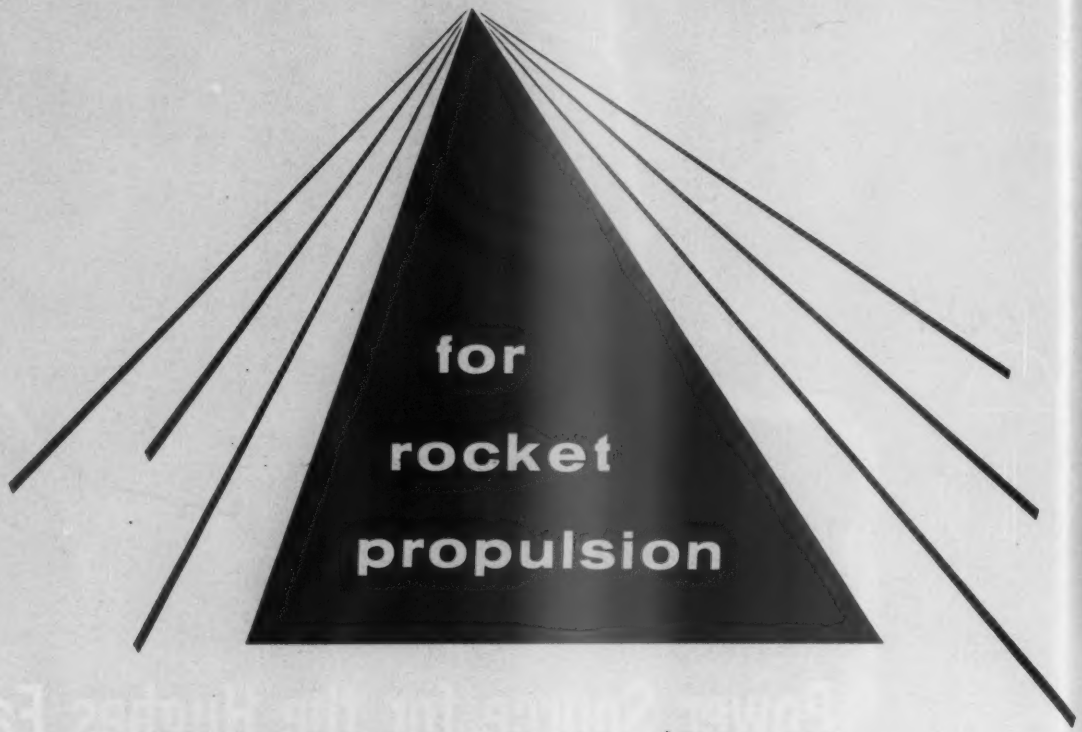

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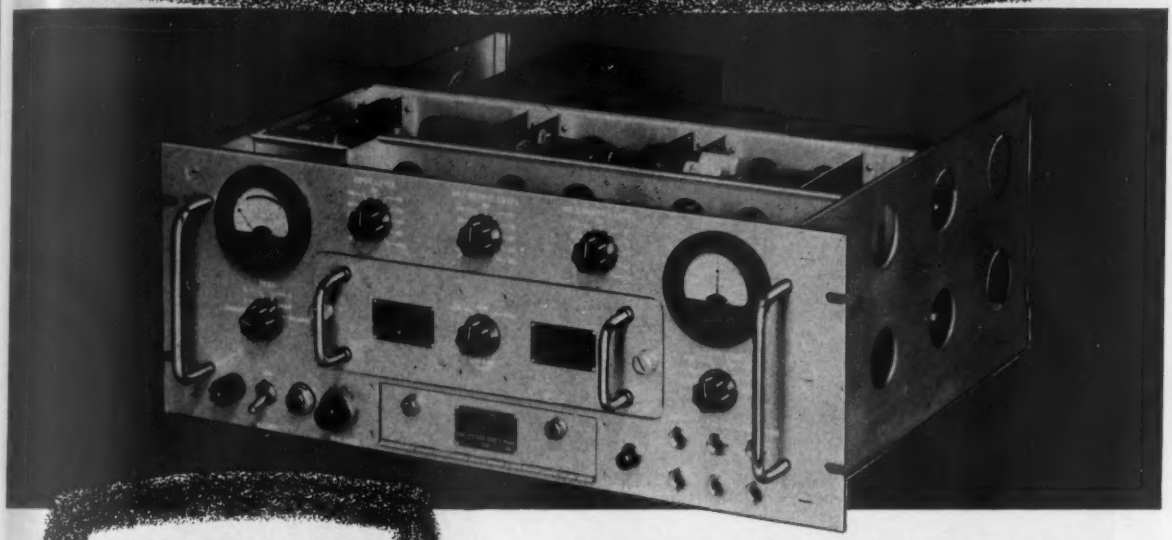

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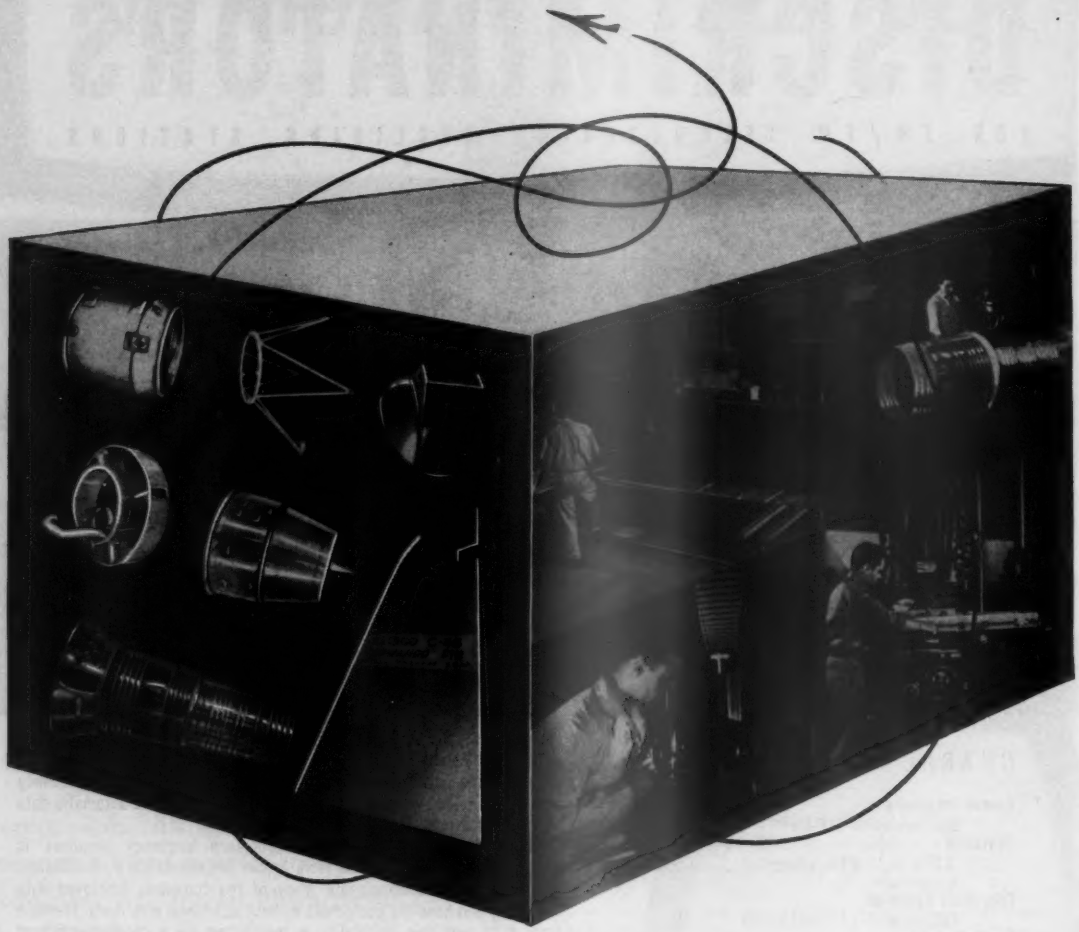

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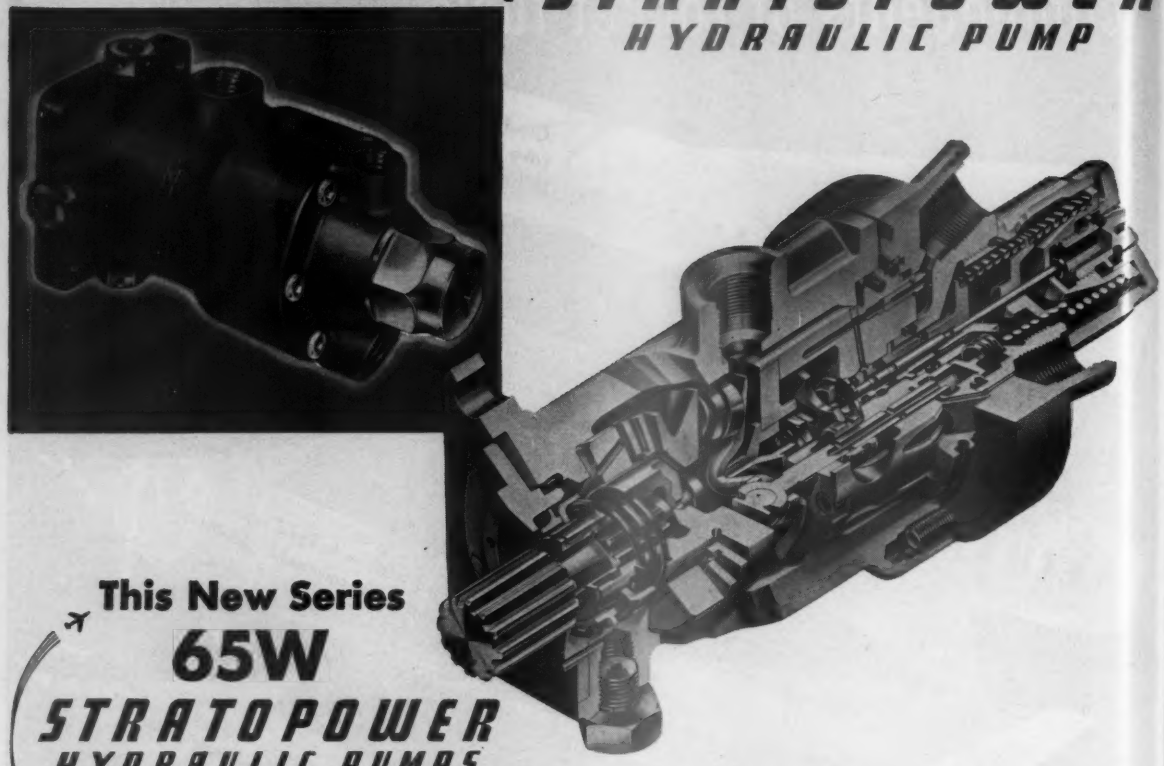

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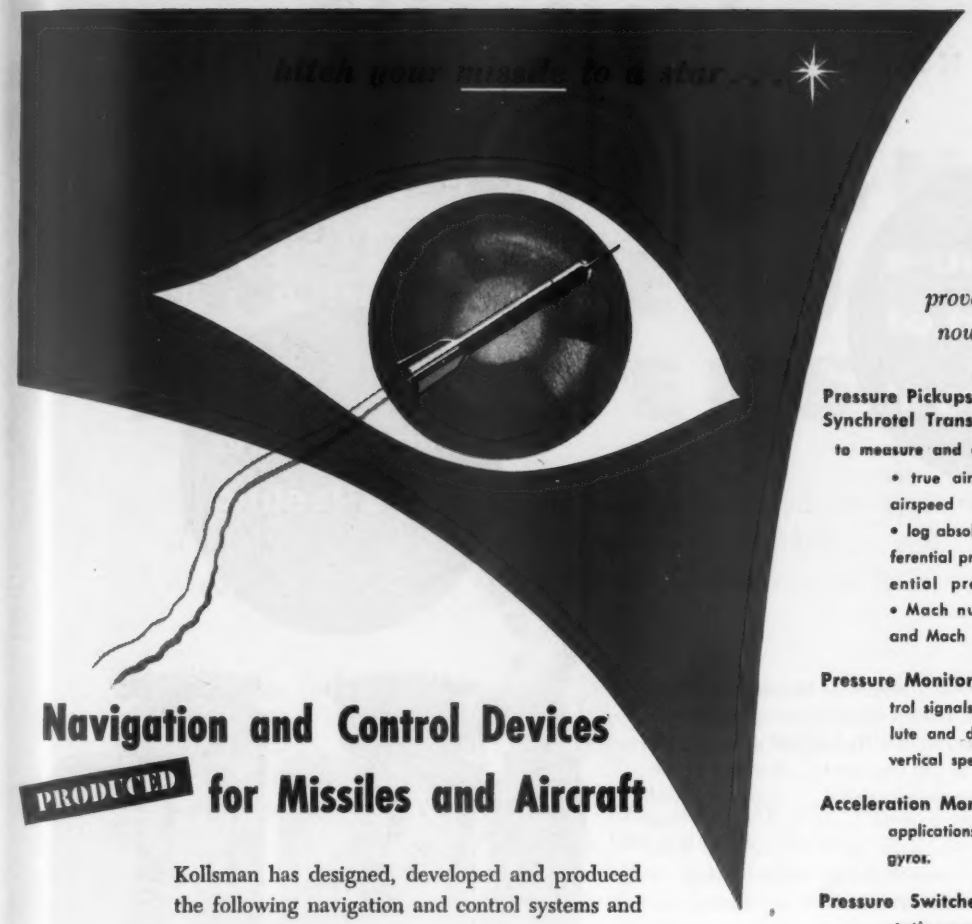

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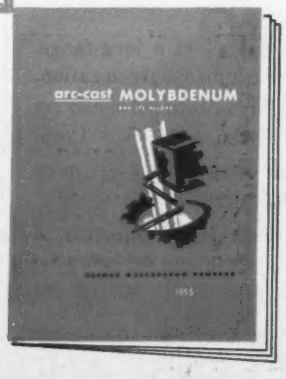

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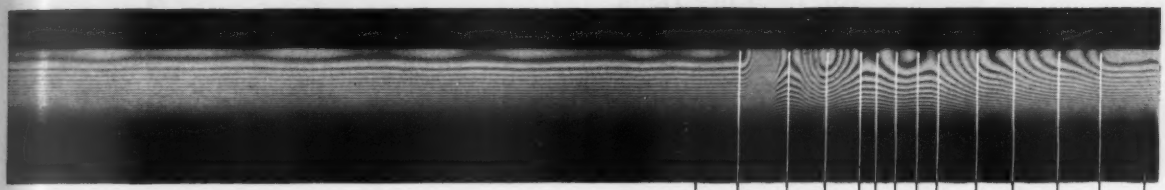

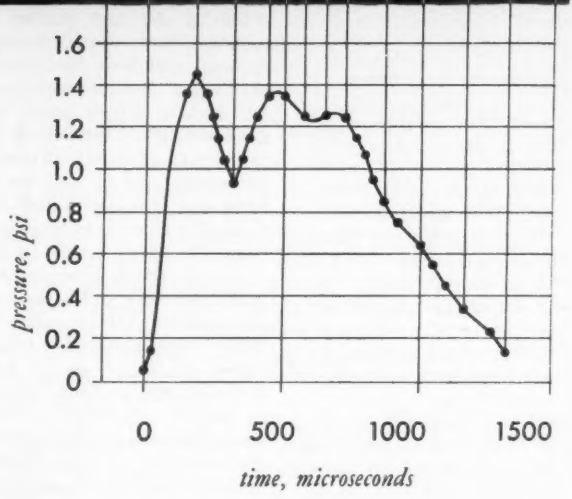

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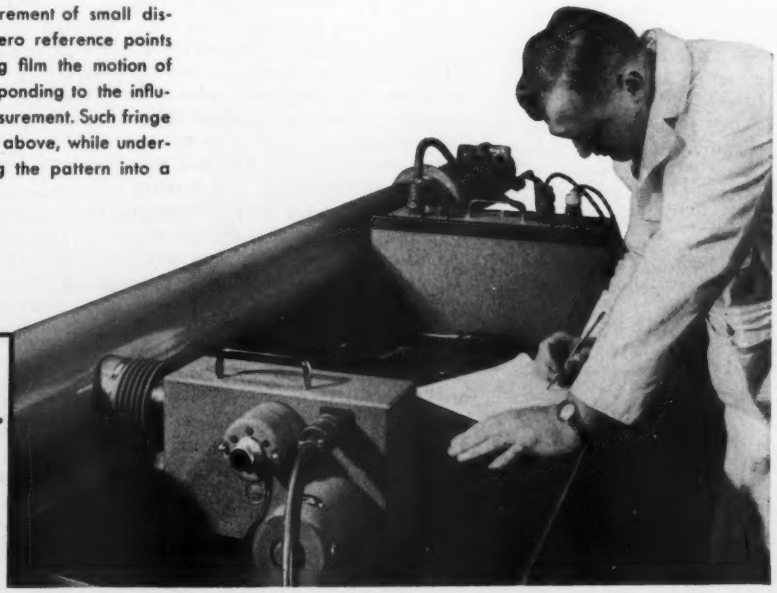

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SAN CARLOS 7, CALIFORNIA

NOVEMBER 1955

VOLUME 25 NUMBER 11

JET PROPULSION

Journal of the AMERICAN ROCKET SOCIETY

Editor-in-Chief

MARTIN SUMMERFIELD

An Anniversary Is a Time for Looking Back

MOST of us seem to find it easier, and certainly more fun, to predict the future than to try to understand the past. In this issue, however, we shall turn our attention backward, I hope not solely for reasons of nostalgia, but rather to learn from the past so that we may better control our future. Where have these years gone? Your years and mine?

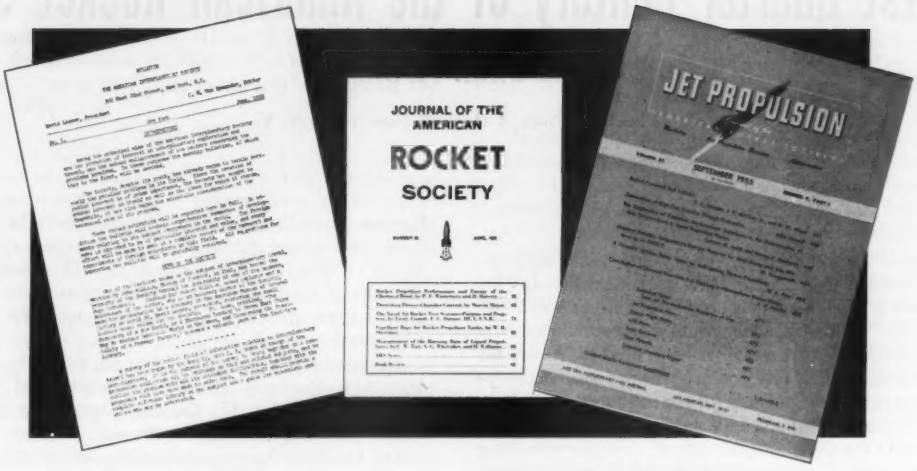
During the past quarter century we survived a great economic depression, we experimented with a controlled economy and discarded it, we fought a great war and won it, then allied ourselves with our conquered enemy against the still greater danger posed by our former ally. We have gone through a period of cynical materialism and have returned to spiritual faith in numbers greater than ever before. Personally, one by one, we learned how much we didn't know and, building on that rather sobering experience, began to acquire some knowledge and a little understanding of the world, the people around us, and ourselves.

The American Interplanetary Society began this period with confidence and assurance which were for the most part unwarranted. Its founders were certain that only a few minor problems and a few years' work separated them from the Great Adventure—escape into space. As their experience increased, the problems looked bigger and the years greater in number. Eventually it became apparent that the engineering development of rocket propulsion must precede any real planning for space flight. And so the Interplanetary Society became the Rocket Society.

The coming of war brought a whole new generation of problems, some of which were made to order for the rocket, some for the newly discovered ramjet, and some for the turbojet. New industries were born, requiring specialists in new technical fields. Many of these specialists looked to the AMERICAN ROCKET SOCIETY as an outlet for their professional activities. The Society responded to this challenge by enlarging its scope to include the development and application of all reaction engines, by increasing its services, and by improving its professional standards, and was rewarded by a phenomenal increase in membership. As a result of more than a decade of hard work on the part of thousands of these professional engineers and scientists, most of whom are now members of our SOCIETY, reaction engines have reached a state of development sufficient for military applications which were not even dreamed about twenty-five years ago. More important in the opinion of many of our members, it is now possible at least to think realistically about space flight.

May the next twenty-five years bring an end to any further need for military work and a beginning of the Space Age, in which man will free himself from the prison of Earth and find out what lies in the great beyond!

Richard W. Porter, *President*



The ARS Journal: Left, 1930; Center, 1951; Right, 1955

Taking Stock. . . .

THE most tangible historical record of the development of the AMERICAN ROCKET SOCIETY is its JOURNAL. Twenty-five years ago the first mimeographed issue of the quarterly *Bulletin of the American Interplanetary Society* appeared. The early numbers provided interesting reading about space flight, rockets, and the solar system for a small circle of engineers and laymen. As rocket technology moved ahead in the following years, research papers appeared with greater frequency in the renamed *Journal of the American Rocket Society*. In the late forties the *Journal* was a pocket-size quarterly, published in a fairly businesslike way, although the Editor often found it necessary to write part of an issue himself when the contributed manuscripts were insufficient to fill the magazine.

In 1951 the Board of Directors voted into effect certain new policies designed to establish the *Journal* on a professional level. The present Editor-in-Chief accepted the responsibility for carrying out the new program, and was joined in this task by a capable group of Associate and Assistant Editors. Financially, the new JOURNAL had to lift itself by its bootstraps. To attract advertisers it had to achieve professional recognition, but this in turn required money that could come only from advertisers.

Today, four years later, it appears that the most difficult problems have been solved. Your JOURNAL is now a monthly; it is circulated, read, and referenced in scientific literature throughout the world; its circulation continues to move steeply upward; its annual publishing capacity has doubled in the last year alone; among its authors are many of the leaders of jet propulsion science and engineering; new feature sections have been added to meet the diverse interests of the membership; its advertising income continues to increase; and, as solid assurance of future growth, the financial statement shows it to be a fairly profitable business for the Society.

From a modest beginning, your JOURNAL has become a substantial institution of national and international importance.

Martin Summerfield, *Editor-in-Chief*

A Commemorative Issue

THE idea to dedicate a special issue of the JOURNAL to the 25th Anniversary of the AMERICAN ROCKET SOCIETY emerged from a suggestion originally put forward by Dr. G. E. Pendray, founder of the ARS, whose interesting account of the formation and growth of the Society appears in the following pages. Now that the Society had completed its first quarter century, it appeared worth while to review the advances in rocketry and in the jet propulsion sciences that paralleled its growth. This is the essential purpose of this commemorative issue.

In the wake of the recent U. S. announcement of the proposed earth satellite, the complete text seems to take on even more significance, for it offers an opportunity to assess anew the scientific and engineering capabilities that prompted the National Academy of Sciences to embark on this bold program in connection with the International Geophysical Year.

The papers in this issue were specially invited by the Editors of the JOURNAL with the preceding ideas in mind, and it is clear that these objectives have been fulfilled. Despite the many great demands on the authors, they cooperated to the fullest extent, even to the point of meeting a rather short time deadline. The Editors wish to thank them for the very fine job they have done. The Society can be proud that authorities in important fields recognize its objectives and are willing to contribute to the pages of the JOURNAL.

The words of the authors say one thing clearly, that the growth of the Society and the technological advances in the fields it represents have been very great indeed. Of this, too, the AMERICAN ROCKET SOCIETY can be proud.

Irvin Glassman, *Anniversary Issue Editor*

The First Quarter Century of the American Rocket Society

G. EDWARD PENDRAY[1]

Pendray, Cook & Hoving, New York, N. Y.

I

ON A balmy spring evening twenty-five years ago, on April 4, 1930, eleven men and one woman gathered in an apartment on the third floor of a small building at 450 West 22nd Street, New York City, to form a new and somewhat ambitious organization. Its name was to be the American Interplanetary Society. Its purpose was the practical development of rockets and jet propulsion, for the conquest of space.

This was obviously no small undertaking especially in view of the fact that of the dozen people present, virtually none had connections or reputation, none were well-off financially, only about half possessed any sort of formal technical training, and only one or two could be considered engineers in any real sense of the term.

History has shown more than once, however, that the course of world events can sometimes be swerved by a mere handful of people—provided they possess energy, persistence—and an important idea.

The organization this group founded in 1930 is now known as the AMERICAN ROCKET SOCIETY. The dozen has become more than 4000. Rockets and jet propulsion have turned technologically respectable. Space flight, while not yet achieved in reality, is close, and already captures the imagination of millions. Rockets have been shot vertically to the edge of space. Guided missiles based on rocket power have taken a leading place in the armamenta of the world. The American rocket and jet propulsion industry involves expenditures of more than a billion dollars annually. The government of the United States is currently backing the first real attempt to launch an artificial satellite into space. And the Society founded in 1930 is now the largest and most influential technical body in its field in the world.

II

The founders of the Society did not, of course, originate the idea of space travel or rocket development.

Twenty-five years ago, rocket discussions and rocket experimentation, all based more or less on the expectation of space flight as the ultimate goal, were going on in many parts of the world and were a common topic of newspaper stories and feature articles.

In France, Robert Esnault-Pelterie, world-famous as an aircraft engineer and manufacturer, had written a scholarly book entitled "L'Astronautique," which gave its name to the then-emerging "science" of astronautics. At Munich, Hermann Oberth had published, in 1923, his first book on space flight, "Die Rakete zu den Planetenraumen" ("The Rocket Into Interplanetary Space"). Soon afterward appeared Walter Hohmann's "Die Erreichbarkeit der Himmelskorper" ("The Attainment of the Celestial Bodies"), and Max Valier's "Der Vorstoss in den Weltraum" ("A Dash Into Space").

In 1926 Willy Ley, later to become one of the organizers of the Verein für Raumschiffahrt (the German interplanetary society) wrote his first rocket and space book, "Die Eahrt ins Weltall" ("Traveling in Space"). In the ensuing five years many other books on rocketry and space flight appeared in Europe, including Russia. Besides technical and popular books, there was published a fictional piece called "Frau im Mond" ("The Girl in the Moon") by Thea von Harbau, then the wife of Fritz Lang, the motion picture director. It was later turned into a popular movie by UFA, the German film company.

Despite all the European furor, the man who had started all this 20th Century interest in rockets and space was an American, Robert H. Goddard, professor of physics at Clark University, Worcester, Mass.

Dr. Goddard had been thinking about rockets ever since his graduate student days at Worcester Polytechnic Institute and Princeton University. About 1914 he began experimenting at Clark University with ship rockets, trying to determine the basic principles of what has since come to be known as jet propulsion.

Interested primarily in the physics of the upper atmosphere, he had first turned to the rocket as a means of sending instruments to high altitudes for scientific information. This interest gradually shifted from the atmosphere to the rocket itself. As Goddard began to develop the basic laws of rocket operation, he began also to see the rocket's potentialities, not only for atmospheric exploration, but for the exploration of space as well.

Goddard was not the kind to rush into print for the mere glory of exploiting an idea. Rather, when he did write, it was for a very practical purpose: he needed financial support for his experiments. His first paper on rockets was put together as a means of enlisting that support. Submitted in manuscript to the Smithsonian Institution in 1916, it won him a $5000 grant from that institution, followed by others in the ensuring years, totaling in all something over $11,000.

Revised and brought up to date in the light of experiments carried on under these grants, Goddard's paper was finally published by the Smithsonian in January 1920. It was a modest sixty-nine page monograph, bound in brown paper, entitled "A Method of Reaching Extreme Altitudes," and issued as a part of the Smithsonian Miscellaneous Collections, Volume 71, No. 2. This classical treatise marked the beginning of the modern era of rocket development, touched off world-wide interest, excitement, and speculation, and led directly to the magnificent developments in rocketry, guided missiles, and jet propulsion of today.

Goddard's subsequent accomplishments are now well known. During World War I he carried on work at Mt. Wilson Observatory with solid-fuel trajectory rockets and demonstrated their possibilities as war weapons—a project that was later to stimulate the enormous development of solid-fuel weapon rockets in World War II.

Shortly after the publication of his Smithsonian paper he turned from solid to liquid-fuel rockets, and shot the world's first liquid-fuel rocket on March 16, 1926, at Auburn, Mass. On July 17, 1929, he shot a liquid-fuel rocket at Auburn which carried a small barometer and a camera to record the readings of the barometer—apparently the world's first instrument-bearing rocket.

Someone who witnessed the 1929 flight from a distance mistook the rocket for a burning airplane and notified the fire department. The result was widespread and, at first,

[1] Senior Partner. Mem. ARS.

unwelcome publicity, resulting in action by the state fire authorities forbidding any further rocket experiments in Massachusetts. But good unexpectedly came of it also. The newspaper stories attracted the attention of Col. Charles A. Lindbergh. He visited Dr. Goddard, and later interested Daniel Guggenheim and his son, Harry F. Guggenheim, in the work of the Worcester scientist. The result was Guggenheim support at a level that made real engineering development possible.

III

Dr. Goddard, accordingly, was busy in 1930 establishing his new Guggenheim-supported rocket research establishment at Mescalero Ranch, near Roswell, N. Mex., and was not among the original founders of the American Interplanetary Society.

In fact, it is extremely unlikely that he had even heard of any of them. For the truth is, that the Society grew out of the then widespread interest in science fiction. Its original members were not so much technical people as writers, whose ideas had been shaped by reading rather than experiment, and whose imaginations could outpace dull practical considerations with a velocity comparable to that of light.

The principal moving spirit of this group was David Lasser, now Research Director of the International Union of Electrical, Radio and Machine Workers, CIO. Mr. Lasser had studied engineering at Massachusetts Institute of Technology, and after a brief career in engineering and industry, had become managing editor of the Gernsback Publications. His major interest at the time was *Wonder Stories*, a Gernsback magazine devoted to science fiction. Then, as now, the art of science fiction attracted a polyglot group of writers, and many of the stories were written—under pen names—by people of not inconsiderable scientific or engineering background.

It was natural that some of the more congenial spirits among such a group should get to know each other, and that speculation about the future would become a principal topic at such gatherings. The most popular theme of science fiction was interplanetary (or interstellar) travel, and some of Mr. Lasser's most active stable of writers began to gather at more or less regular intervals at the Pendray apartment. In the basement of this building at that time an excellent speakeasy was in operation, and suitable quantities of red wine could be obtained to render space discussions truly memorable.

The one woman present on the occasion of the founding of the Society was Mrs. Pendray, then a widely syndicated newspaper writer whose columns appeared under several pen names, including Leatrice Gregory, her maiden name and the name by which she was known professionally. She later served for several years as the Society's librarian. She also designed and sewed the parachutes used in the Society's first rockets. I was a newspaper reporter on the *New York Herald Tribune*. Both of us had been drawn into the group through my own science fiction efforts, which had included a full-length novel called "The Earth Tube," published by D. Appleton, and several stories and novelettes published in *Wonder Stories*, all under the pen name of "Gawain Edwards."

Others present that evening were C. P. Mason, who was employed by the Gernsback organization; C. W. Van Devander, a New York newspaperman who became a successful Washington columnist, and is now Press Secretary for Governor Harriman; Fletcher Pratt, the writer and naval expert; the late Nathan Schachner, a well-known writer and biographer; Laurence E. Manning, a writer and businessman, now head of the Kelsey Nursery Company of Highlands, N. J.; William Lemkin, now a teacher of chemistry at Fort Hamilton High School, Brooklyn; and three young men: Warren Fitzgerald, Everett Long, and A. L. Fierst, whose present whereabouts and occupations I have been unable to ascertain.[2]

[2] None of the original founders is now a member of the Society except Mr. Pendray.

Lasser was the first president of the Society. He quickly drew up a constitution, and began to plan public meetings. I was elected vice-president, and given the assignment of organizing a research program. Fletcher Pratt became the Society's first librarian, and C. P. Mason, its first Secretary. Mr. Van Devander became the first editor of the Society's publication, the *Bulletin*.

IV

So real, important, and close-at-hand did the space flight objectives of the Society seem to us in those far-off, naïve days, that the organization's first name appeared neither fantastic nor pretentious; indeed, it was felt that any less ambitious name would soon be outmoded. We believed generally that a few public meetings and some newspaper declarations were all that would be necessary to bring forth adequate public support for the space-flight program. As for technological help, it was our expectation that engineers and scientists would spring to our service if we but called their attention to the possibilities of rockets in an appropriate manner.

It seemed singularly fitting, therefore, that the Society's first public activity would be to arrange a ceremony at the American Museum of Natural History, at which Captain Sir Hubert Wilkins, the polar explorer, could present to the Society's "library" an old copy of one of the earliest works on interplanetary travel, "The Discovery of a New World," by John Wilkins, Bishop of Chester, written in 1860.

Bishop Wilkins was an ancestor of Sir Hubert's. The copy of the book he presented to the Society had been dug up by Lasser in a second-hand bookstore. The ceremony attracted a very satisfactory amount of publicity, since Sir Hubert at that time was not only famous but had just returned from a newsmaking voyage of exploration to Antarctica. But the publicity brought neither public support for interplanetary research nor any offers from established scientists or engineers to make common cause with us.

Nothing daunted, we proceeded to plan a much more spectacular operation. Lasser had learned that Esnault-Pelterie, who had gained considerable reputation because of "L'Astronautique" and his lectures on rockets and interplanetary flight, would presently visit this country. Lasser cabled asking him to address a public meeting under our auspices. Somewhat to the Society's astonishment, he accepted.

Arrangements were made to use the auditorium of the American Museum of Natural History for the meeting. This auditorium holds about 1200—a very large crowd for an unknown and impecunious organization to draw. So as an added attraction it was arranged with UFA's New York office to show a part of "Frau im Mond," the Fritz Lang movie based on Thea von Harbau's novel, which had been retitled in English and brought out in this country under the title "A Girl in the Moon." The Society's serious-minded executive group impatiently cut out the romantic parts of the story and retained only the technical portions, showing the fictional space rocket (based on designs by Oberth), the take-off, and the space flight itself.

The double attraction was widely placarded throughout the city. Owing to the newspaper connections of some of the Society's charter members, it received considerable advance publicity as well. Long before the time of the meeting there was ample evidence that the auditorium would be well filled. In fact, the museum authorities, fearing an unmanageable crowd, insisted on employing extra guards, thus inflicting almost mortal injury upon the Society's treasury.

Everything was set for a big meeting—and then Esnault-Pelterie, who had arrived on schedule, and worked with the Society's officers on the preparation of his speech, sent a devastating note. He had a sudden cold, and could not make the address. This bombshell arrived just four hours before the scheduled time of the meeting.

It was decided that a member of the Society would have to give Esnault-Pelterie's talk in his place. I was the man elected to do it. Lasser, as chairman of the meeting, announced the substitution in an unmistakable way, but nevertheless many members of the audience came clamoring up to the rostrum afterward, demanding Esnault-Pelterie's autograph. After several fruitless efforts to explain that I wasn't the great Frenchman in person, I gave up and signed Esnault-Pelterie's name right and left. As a result of that night's work there are hundreds of copies of Esnault-Pelterie's signature in autograph collections today that couldn't be phonier.

In any case, the Society found itself well launched. The membership climbed from 12 to more than 100. Some well-known names in science and technology did begin to show up in the list, including those of H. H. Sheldon, professor of physics at New York University; Alexander Klemin, head of the Guggenheim School for Aeronautics at New York University; John O. Chesley, in charge of new developments for the Aluminum Company of America; George V. Slottman, now vice-president of the Air Reduction Company; and James M. Kimball, head of the New York office of the U. S. Weather Bureau. Dr. Goddard also joined the Society at this time, though at first he took no active part in it. (At the time of his death, in 1945, he was a director.)

V

Within three months the Society was able to begin publication, at first in mimeograph form, of its *Bulletin*—later called *Astronautics*, then *The Journal of the American Rocket Society*, and now JET PROPULSION.

The first issue was published in June 1930. It consisted of four single-spaced pages, carrying news of the Society's founding, the "gift" of the Wilkins book, a summary of a paper on "The Historical Background of Interplanetary Travel" by Fletcher Pratt, an item about the tragic death of Max Valier, the German rocket pioneer, which had occurred the previous month; a predition by Esnault-Pelterie that "a trip to the Moon may be possible within 15 years."

There was also an announcement that the Society was undertaking "a survey of the entire field of information relating to interplanetary travel. . .to outline the problem with all its attendant difficulties, together with the proposals that have been made to solve them." The result, wrote the editor, "should provide a complete reference library on the subject and a guide for scientists and others who may be interested."

Early in 1931 it became possible for Mrs. Pendray and me to go abroad. Pursuing my assignment to get a research program going, we planned the trip in such a way as to enable us to see what the European experimenters were doing. The Society named us as its official representatives. But in view of the state of the treasury, we paid for the trip ourselves.

After unsuccessful attempts to contact several experimenters in Italy and France who had been attracting newspaper attention but providing little technical detail on their activities, we at length arrived in Berlin. There we found Willy Ley, very much at home and eager to show us the work being carried on by the Verein für Raumschiffahrt at the "Raketenflugplatz"—the VfR's "rocket flying field" on the outskirts of Berlin, at Reinickendorf.

We had not previously met Ley, but had carried on a correspondence with him. We found him an enthusiastic, tireless, quick-minded, and imaginative young man, eager to please and very helpful. The only problem was that his English wasn't very good at that time, and our German was nonexistent. It was not easy to carry on technical conversations that were fully understood by either side.

However, Ley and his VfR associates gave us the most memorable experience of our trip, an actual proving-stand test of a small liquid-fuel rocket motor, using gasoline and liquid oxygen. We were not aware at the time that Goddard's successful shots since 1926 had been accomplished with liquid fuels, and this experiment at the Raketenflugplatz was the first of its kind we had ever witnessed. It filled us with excitement, and upon our return we reported fully to the Society, on the evening of May 1, 1931, both the method and promise of the German experiments.

VI

Shortly after the May meeting, H. F. Pierce (who was later to become president of the Society and one of the four original founders of Reaction Motors, Inc.) proposed that we delay no longer the beginning of our own experimental program. An Experimental Committee was formed with myself as chairman, and the Society's Rocket No. 1 was designed by Pierce and me by rule-of-thumb, assisted by faith. It was patterned generally after the "Two-Stick Repulsor" rocket of the VfR, plans for which I had discussed with Ley in Berlin.

American Rocket Society Rocket No. 1

Being prepared for firing tests at a field near Stockton, N. J., November 12, 1932, by H. F. Pierce (left) and G. Edward Pendray, co-designers of the rocket.

Construction was carried on in a small shop Pierce had established in the basement of the apartment house in which he lived, in the Bronx, N. Y. The rocket was to consist of two parallel cylindrical tanks of standard aluminum piping, each $5\frac{1}{2}$ ft long and 2 in. in diameter. They were held at the top by a framepiece which supported the motor and its cooling jacket, turn-on valves that could be operated electrically from a distance, and a cone-shaped nosepiece containing a parachute. At the rear of the rocket were large sheet-aluminum fixed vanes for guiding in vertical flight.

The fuels were gasoline and liquid oxygen, forced into the motor at approximately 300 psi by gas pressure: the oxygen by its own pressure produced by partial evaporation, the gasoline by nitrogen supplied from an auxiliary tank. The

parachute mechanism was kept closed by gas pressure in the gasoline tank, and was set to spring open when the pressure went off, after the termination of firing.

The motor itself was an aluminum casting, 3 in. OD and 6 in. long, with walls $1/2$ in. thick. It was one of several made for us without charge by the Aluminum Company of America, machined and drilled for fuel inlets and other fitments by Pierce in his basement workshop. It was encased in an aluminum water-jacket shaped like a cocktail shaker—it was, in fact, a shaker given away by one of the chocolate-milk companies as a premium. The holder for the parachute was a ten-cent store aluminum saucepan, fitted with a hinge and spring for ejecting the chute.

Loaded with fuel, this first ARS rocket weighed 15 lb, and was a wonderfully and fearfully made device. The motor was calculated to provide a thrust of 60 lb, giving an expected acceleration at the launching of 3 g.

The rocket received its first burning test on November 12, 1932, on a farm owned by a relative of Mr. Lasser's near Stockton, N. J. Members of the Society had hauled lumber and built a small wooden launching rack, equipped with a spring-operated thrust-measuring device. The motor burned satisfactorily between 20 and 30 sec, and provided the expected 60 lb maximum thrust, as well as it could be measured on our crude apparatus.

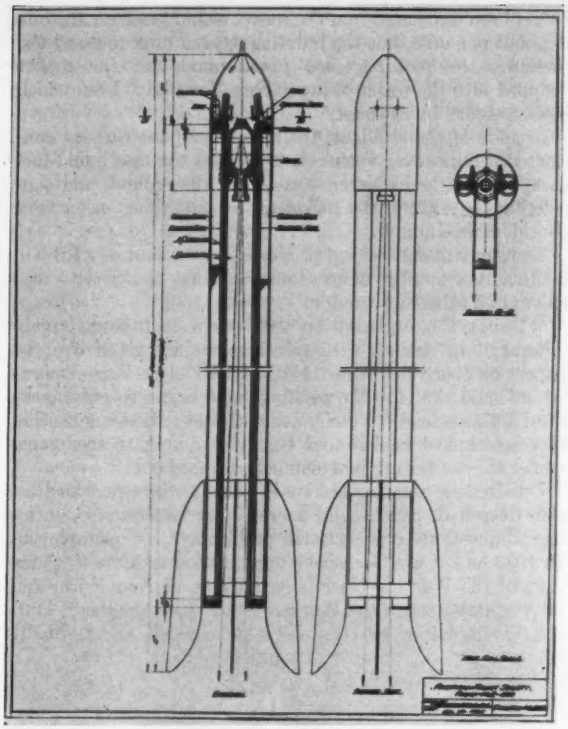
The Society's First Proving Ground

Site, on a farm near Stockton, N. J., where ARS Rocket No. 1 was given static tests on November 12, 1932. Launching tower was made of wood. In foreground, by sandbags, Miss Leatrice Gregory (Mrs. G. Edward Pendray), one of the founders of the Society and an official photographer at this test.

During these ground tests, however, the rocket was accidentally damaged, and as a consequence it was never flight-tested. Its fragility, and the difficulty of getting all of the parts to operate satisfactorily at the right time, caused the members of the experimental group to decide on a thorough reconstruction, of such a radical nature as to constitute making it into a new rocket.

This task was put into the hands of Bernard Smith, a young member with considerable mechanical aptitude, who is now Head of the Surface Weapons Division, Naval Ordnance Test Station, China Lake, Calif. Smith removed the awkward superstructure containing the parachute, the useless water jacket, and other items that had proved to have no value. He clamped the motor securely between the two tanks, substituted light balsa-wood fins for the aluminum vanes, and rounded the forward end of the rocket with a streamlined bonnet containing a large port for air cooling.

This rocket, known as ARS Rocket No. 2, was shot from a temporary proving field at Marine Park, Great Kills, Staten Island, N. Y., on May 14, 1933. It reached an altitude of about 250 ft, after firing about 2 sec, and was still going strong when a stuck valve caused the oxygen tank to explode.



Design for ARS Rocket No. 2

The plan as drawn up by Bernard Smith, who constructed this rocket from the tanks and motor of ARS Rocket No. 1.

Flight of ARS Rocket No. 2

The shot, at Marine Park, Great Kills, Staten Island, N. Y., on May 14, 1933. The rocket's igniting equipment failed to work, and it was lighted personally by Bernard Smith, with a gasoline torch. He was unable to get back under the protection of his barricade before the beginning of the shot. Other spectators had the doubtful protection of a few sandbags at the water's edge. The rocket reached an altitude of about 250 feet before a bursting oxygen tank brought the shot to an abrupt end.

It had been calculated that the rocket would reach an altitude of about one mile, but the bursting oxygen tank released the pressure, the motor ceased functioning, and the rocket dropped into the water of lower New York Bay, from which it was rescued by rowboat.[3]

In spite of the accident, the members of the Society considered it a most successful shot. It was the first liquid-fuel rocket any of us had ever seen get off the ground, and considering the state of the rocket art at that time, was a very considerable triumph.

The surge of enthusiasm produced by the shot of ARS No. 2 brought a number of new members into the Society and galvanized others into action.

Whereas the organization until then had been largely "literary" in nature, with meetings mainly given over to papers on space flight, historical reviews of rocketry, speculations, and the like, the meetings now began to grow technical and practical. Young men with specialized engineering and mechanical background began to dominate the scene, while many of the original members dropped out.

One of these was Lasser himself, who, as the Great Depression deepened, had become increasingly interested in sociological questions, especially the problems of the unemployed. In 1933 he left the Gernsback organization to serve as chairman of the Workers Unemployed Union of New York, and later as president of the Workers Alliance of America. During this period his interest in rockets lessened, and he finally began to devote his full time to other interests.

VII

Meantime, such men as John Shesta, Bernard Smith, Lovell Lawrence, James Wyld, Alfred Africano, and Roy Healy were joining the Society, bringing with them not only the outlook, methods, and training of engineers, but also the kind of youthful zeal and enterprise which had proved so sadly lacking in the older technical men we had previously sought to enlist in rocketry's cause.

Plans for new rockets began to burgeon. Designs for three most promising ones were quickly approved by the Experimental Committee, and announced in *Astronautics* for October 1933.

The design designated as ARS Rocket No. 4, constructed by John Shesta and a small committee he had selected to aid him, was completed first. Its motor was placed ahead of the center of gravity as in the case of all these early rockets, on the theory that greater flight stability could be achieved in that way. It had four nozzles, so placed as to shoot the jet gases downward but slightly away from the sides of the gasoline tank on which the motor and its support were perched. The oxygen tank was fastened directly behind the gasoline tank. A small cylindrical case for a parachute projected ahead of the motor. It was an extremely sturdy and well-built rocket, showing the kind of careful workmanship for which John Shesta has become noted.

The first attempt to shoot ARS Rocket No. 4 disclosed that the fuel inlet ports were not large enough, and the rocket failed to rise. At the second attempt, on September 9, 1934, after the rocket had been repaired and the fault remedied, it emerged from the launching rack most satisfactorily. In flight it performed well for the first few seconds, then one of the nozzles burned out. The rocket went into a long trajectory over the bay, and struck the water still firing. The calculations of observers at three triangulation stations, aided by motion picture and still photographers, were that the maximum speed of this rocket exceeded 1000 ft per sec.

Rocket No. 3, designed by Bernard Smith and myself, was completed next. In this one, the fuel tanks were nested one inside the other, rather than running tandem, as in the Shesta design. It was compact, and had many theoretical advantages, but was extremely troublesome to construct because of the difficulty of soundly welding the numerous seams, some of them internal. When it was finished, we learned the discouraging fact that it was next to impossible to fuel it, because the liquid oxygen, exposed to so much warm metal in the large outer tank, simply evaporated as fast as it could be poured in.

ARS Rocket No. 4

Making final adjustments before the shot, on September 9, 1934, at Marine Park, Great Kills, Staten Island, N. Y. Left to right: John Shesta, who designed and built the rocket; Carl Ahrens, a member of the Experimental Committee; G. Edward Pendray, chairman of the Experimental Committee.

This rocket could undoubtedly have been loaded and shot, perhaps by some such method as precooling it with dry ice. But by the time it was ready for testing, it had already become apparent that solid motors such as were used in these experimental rockets simply could not stand up to more than a few seconds of firing, and that some way would have to be developed to make a motor that would not burn out.

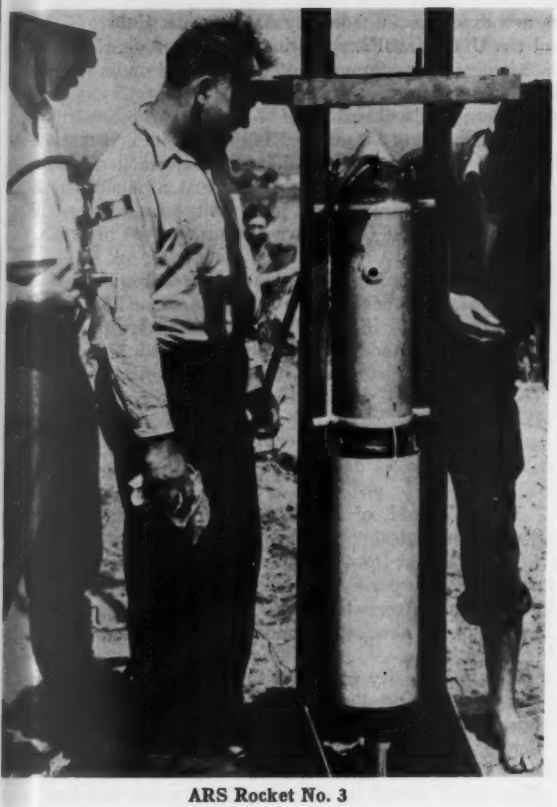
The experimental committee had already developed a proving stand program for tackling this problem directly, and had assigned John Shesta to construct the Society's first proving stand, which he made from parts of his ARS No. 4 rocket. Construction of the projected ARS No. 5 rocket, designed by H. F. Pierce, Nathan Carver, and Nathan Schachner, was abandoned.

VIII

Then began a long and often discouraging, but finally successful, series of proving stand tests, carried on in various spots under very great difficulties.

These tests provided much data and experience, and cul-

[3] All proving fields of the ARS were "temporary" at that time, since legal permission for such tests was unobtainable, and the police frequently arrived during tests, threatening arrests and forbidding further shots. As a result, almost every test required the finding and preparation of a new testing site.



ARS Rocket No. 3

The rocket being pressurized preparatory to static tests at Marine Park, Great Kills, Staten Island, N. Y., September 1934. Left to right: John Shesta, a member of the ARS Experimental Committee; G. Edward Pendray, chairman of the Committee and co-designer of the rocket, and Bernard Smith, who designed and constructed the rocket.

minated in the development of a practical liquid-cooled regenerative motor by James Wyld, which in turn directly led to the founding of Reaction Motors, Inc., by Lawrence, Shesta, Wyld, and Pierce, all of whom were active in the experimental program.

Until that time the Society had been using cast aluminum motors, some cooled with water, others depending on the heat that might be soaked up in the metal mass during the relatively short interval of fire. In the tests, motors and nozzles of steel, stainless steel, Nichrome, carbon, "hard surfacing," and other heat resistant materials were tried. Various members suggested tests to be run, or constructed motors to be tested. The proving grounds changed often, because of interference from the neighbors, the police, and other considerations.

The first series of runs was undertaken at Crestwood, N. Y., on April 21, 1935. Five motor shapes were shot on that occasion, all being similar in general pattern to those already used or planned for the Society's rockets. None stood up under test.

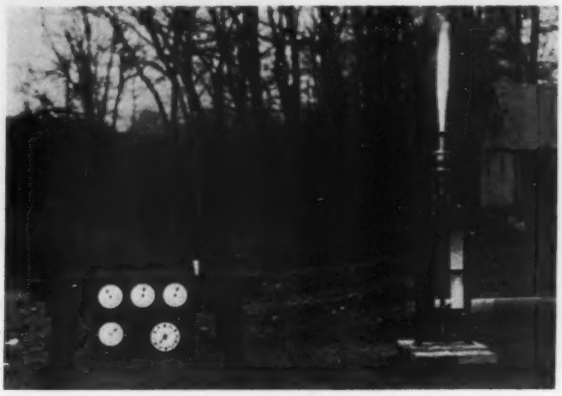
Three months later, a new series of motors was ready. To simplify the problem of changing styles, shapes, and nozzle materials, a sectional motor had been constructed, the nozzle and body sections of which could be exchanged readily after each run. Six runs were made in the second series of tests, also at Crestwood. A Nichrome nozzle stood up well in this series, but not perfectly. All the others burned out.

A third series of tests was shot on August 25, 1935. There were five runs, this time testing various fuels as well as nozzles and cooling systems. A fourth series of tests was made on October 20.

By this time, a great deal of information had been obtained which was beginning to result in new and better motor designs. It had been definitely decided that water would not work as a coolant in these small solid motors, and that alcohol was a better fuel than gasoline. The tests also indicated that the Society's first proving stand, while practical for short runs and motors of less than 100 lb thrust, was too small for the sort of tests now indicated. Shesta was asked to build a new and better stand, aided by Wyld, Africano, van Dresser, and others. The group immediately started work on this project.

During the period required for completion of the new stand, the Experimental Committee turned to the problem of aerodynamic design, and began a series of tests with dry-fuel rockets of many sizes and shapes in an attempt to determine empirically the laws of stability in flight, and the proper mechanics of catapults and other launching schemes, flight stabilizing devices, and parachutes and parachute releases.

These tests were carried on at several sites, principally one near Pawling, N. Y. The dry-fuel rockets tested were made by members of the Society, and consisted of head drive and tail drive types, long ones, short ones, finned and unfinned rockets, and many variations. Tests continued at intervals over about four years, beginning in the summer of 1935 and continuing until November 1939.



ARS Proving Stand Motor Tests

Closeup of a test in progress at Crestwood, N. Y., summer of 1935. Dials mounted on sawhorse register pressure in the fuel and oxygen tanks, pressure in the motor, thrust in pounds, and time in seconds. Dials were permanently recorded by motion picture camera (not shown).

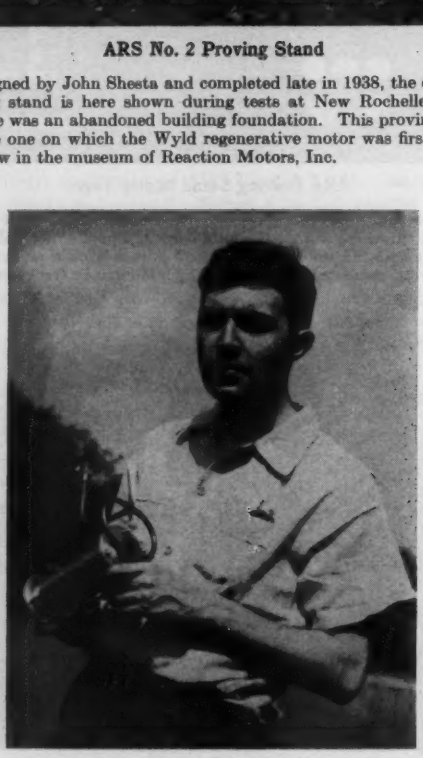
ARS Aerodynamic Rocket Tests

Left to right: John Shesta, Roy Healy, G. Edward Pendray, and Alfred Africano, all members of the ARS Experimental Committee, with solid-fuel rockets of various shapes and sizes, before aerodynamic tests near Pawling, N. Y., summer of 1935.

During the latter part of this period the motor tests also were resumed, and now began to repay the effort. Motors of increasing effectiveness and sophistication began to appear. The Wyld regenerative motor, most successful of them all, was first presented in idea form in an article by Mr. Wyld, with the design for illustration, in the April 1938 issue of *Astronautics*. The same issue carried an article describing a new experimental motor by Midshipman Robert C. Truax of the U. S. Naval Engineering Experiment Station, and an account of its performance at tests carried on at Annapolis, Md.

ARS No. 2 Proving Stand

Designed by John Shesta and completed late in 1938, the enlarged proving stand is here shown during tests at New Rochelle, N. Y. The site was an abandoned building foundation. This proving stand was the one on which the Wyld regenerative motor was first tested. It is now in the museum of Reaction Motors, Inc.



James Wyld and his Regenerative Motor

Photo taken at a test of the motor at Midvale, N. J., on June 8, 1941. This successful motor, developed in the course of ARS Experimental Committee tests, became the basis for the organization of Reaction Motors, Inc.

Following his disclosure of the idea, Wyld constructed a working model of his motor. It received its first test on the Society's new proving stand, at New Rochelle, N. Y., on December 10, 1938, delivering a thrust of somewhat more than 90 lb and producing a jet velocity of well over 6000 ft per sec. Because of an oxygen shortage, the first run was short, only about 13½ sec.

The Wyld motor was subsequently tested in runs at Midvale, N. J., on June 8, 1941, and again on June 22 and August 1. Several other interesting motors also were shot at these tests, including models submitted by Alfred Africano, Robertson Youngquist (then at Massachusetts Institute of Technology), and Nathan Carver.

IX

World War II, of course, brought the American Rocket Society its greatest opportunity—and its greatest hazard.

For suddenly, from a few lone voices crying in the wilderness, rocket experts and rocket enthusiasts seemed to be popping up everywhere. Rockets were being developed wholesale, and rocketry almost overnight became a major industry.

The opportunity presented to the Society by all this was growth and leadership; but the hazard was that, among the hundreds of new rocket technologists entering the field, the Society was relatively unknown. And unfortunately to some who did know of it, its technical reputation was not what they felt it should be. For the ARS, which had been kept alive these many years by the magic of the interplanetary idea, now stood in danger of extinction because of association with that very idea. Interplanetary flight was still not technologically respectable in the 1940's in many quarters.

This danger had been recognized as far back as 1934, when the Society was renamed the American Rocket Society. As the editor of *Astronautics* explained at the time: "In the opinion of many members, adoption of the more conservative name, while in no way implying that we have abandoned the interplanetary idea, will attract able members repelled by the present name."

Another problem threatened the Society's continued existence in the 1940's. In the nature of things, though the ARS had always been national in scope and pretensions, in actuality it was predominantly an East Coast organization. When war rockets burgeoned in the 1940's, a new and powerful galaxy of rocket engineers began to congregate on the West Coast, and there was talk of starting an independent society there.

In the West Coast group, centering mainly around the California Institute of Technology and the Aerojet Engineering Corporation, were such prominent figures as Theodore von Kármán, Andrew Haley, Fritz Zwicky, Clark Millikan, and Dan Kimball; a formidable leadership indeed, should it turn its energies to the formation of a competing society.

The danger, however, was met with consideration and common sense. One evening at the Engineers' Club in New York a private dinner was given by the Board of Directors of the Society. Among the guests were some of the foremost men in American rocketry at that time. Those attending included Goddard, von Kármán, Haley, Lawrence, Shesta, Wyld, Pendray, and several others, including representatives of the Army, Navy, and Air Force. The discussion continued well into the night, and though it appeared at the time to have been inconclusive, thereafter the talk of forming a new organization languished and finally died, and members of the West Coast group began to join the Society.

The organization was still too small and localized, however, to take its rightful place of leadership in the swiftly growing national swing to rockets and jet propulsion. Some sort of affiliation with a strong, well-organized national engineering society seemed indicated. This had been talked over among the members of the Board of Directors, but no action taken.

On the evening of March 7, 1945, I was in Washington to make a talk on rockets before a meeting sponsored by the Washington Society of Engineers. At the meeting was Clarence E. Davies, Secretary of the ASME, and we fell to discussing the ARS and its future possibilities and needs. Mr. Davies suggested the exploration of a possible affiliation between ARS and ASME.

Twenty-three days later, on March 30, Ernest Hartford, of the ASME, reopened the discussion at the suggestion of Mr. Davies. The result was the appointment of a joint committee representing ARS and ASME to work out details of a possible relationship. This group met at luncheon at the Engineers' Club on August 14, 1945 to begin the discussions. Representing ARS were myself, Lovell Lawrence, and John Shesta. Representing ASME were Ernest Hartford, Tom Sawyer, Rudolph Gagg, and L. N. Rowley.

Our final plan for affiliation, which maintained complete autonomy and independence for the ARS, while at the same time obtaining the benefits of close cooperation with one of largest engineering organizations in the world, was completed on September 26, 1945. It was presented to the ASME Executive Committee on October 7, and to the ARS Board of Directors on November 2. Both bodies approved it for a five-year trial period, as of November 2, 1945. It has since been renewed, and the affiliation ultimately may become permanent.

One of the first benefits of the new affiliation was a better address and more adequate office space for the Society. Its headquarters were moved to the Engineering Societies Building, 29 West 39th Street, New York, N. Y., in January of 1946. Membership continued to increase. The Society's activities grew. The *Journal* became a bimonthly; then a monthly, under the new name of JET PROPULSION. The Society took increasing part in technical meetings, participating not only in its own sessions, but also in those of ASME, the Institute of the Aeronautical Science, and others.

By mid-1954 it had outgrown its space in the Engineering Societies Building and now has quarters at 500 Fifth Avenue, New York. The American Rocket Society is currently the largest technical organization devoted wholly to rockets and jet propulsion in the world. The dreams of its founders, including the conquest of space, now begin to appear on the verge of realization.

X

During its 25 years of existence, the Society has had the leadership of many able men, and at each stage has been fortunate enough to find and interest the sort of people who could best advance its progress

In all, it has been served by 18 presidents. Several presidents have served more than one consecutive term, and two, G. Edward Pendray and Roy Healy, served on two different occasions as well.

(1) David Lasser, June 1930–May 1932; (2) G. Edward Pendray, May 1932–September 1932 (resigned before the end of the term in order to devote more time to the ARS experimental program, then engaged in building and launching the first ARS liquid-fuel rocket); (3) Nathan Schachner, September 1932–April 1933; (4) Laurence E. Manning, April 1933–April 1934; (5) G. Edward Pendray, April 1934–April 1936; (6) John Shesta, April 1936–April 1937; (7) Alfred Africano, April 1937–April 1940; (8) H. Franklin Pierce, 1940–1942; (9) Roy Healy, 1942–1943; (10) Cedric Giles, 1943–1944; (11) James H. Wyld, 1944–1946; (12) Lovell Lawrence, 1946–1947; (13) Roy Healy, 1947–1948; (14) Charles A. Villiers, 1948–1949; (15) William L. Gore, 1949–1951; (16) H. R. J. Grosch, 1951–1952; (17) C. W. Chillson, 1952–1953; (18) Fred C. Durant, III, 1953–1954; (19) Andrew G. Haley, 1954–1955; (20) Richard W. Porter, 1955.

The official publication of the Society has regularly appeared, though under various names, since the first issue in June 1930. It is probably the oldest continuously published journal in the world devoted entirely to the technology of rockets and jet propulsion.

It appeared originally as the *Bulletin*, in mimeograph form. The first issue was turned out by Mr. Lasser personally on a borrowed mimeograph machine. The second and subsequent issues were turned over to professional mimeographers. About 100 copies of *Bulletin* No. 1 were printed, and the edition was soon exhausted. The ARS has since reprinted it by facsimile, under pressure of the demand from collectors.

The *Bulletin* was first printed from type in April 1932. The name was changed to *Astronautics* in May 1932 (No. 19), the editor (David Lasser) explaining that the change had been approved by the Board of Directors "since this term (astronautics) most fittingly embraces the complete scope of the planned activities of the Society."

The Great Depression caught up with the Society in the following year, and *Astronautics* had to return to mimeograph and offset printing from typewritten manuscript from May 1933 until November 1934. It was reproduced by printing from type again in June 1935, and has been so printed ever since.

In March 1945, the name of the publication became the *Journal of the American Rocket Society*, and was published as a bimonthly. In January 1954 it assumed its present name, JET PROPULSION, and became a monthly in January 1955.

The publication has been served by thirteen different editors, in fourteen editorships:

(1) C. W. Van Devander, 1930–1931; (2) Clyde J. Fitch, 1931–1932; (3) David Lasser, 1932–1933; (4) G. Edward Pendray, 1933–1935; (5) Peter van Dresser, 1935–1937; (6) Peter van Dresser and James H. Wyld, March 1937–July 1937; (7) G. Edward Pendray, 1937–1939; (8) Roy A. Healy and James R. Glazebrook, 1939–1940; (9) Roy Healy, 1940–1944; (10) Cedric Giles, 1944–1946; (11) Louis Bruchiss, 1946–1948; (12) James R. Randolph, 1948–1949; (13) Robertson Youngquist, 1949–1951; (14) Martin Summerfield, 1951– .

Twenty-five years is a full generation, as the demographers count it—and it may well seem a long time by any human standards. By this date the founders of the Society had fully expected at least one operating colony on the Moon, with preparations under way for voyages further into space. They mistimed their expectations—but what will the next 25 years bring? At the accelerated pace of rocket development these days, their timetable may prove not to have been so far afield, at that.

Twenty-Five Years of Rocket Development

HOWARD S. SEIFERT[1]

Ramo-Wooldridge Corporation, Los Angeles, Calif.

A Forces Guiding Rocket Motor Evolution

The War

THE most prominent event in this quarter century, and the one responsible for the present accelerated state of rocket engine development, was World War II, which neatly divided the life span of the AMERICAN ROCKET SOCIETY into two equal parts.

The period 1930–1940 was one during which the development of rockets was in the hands of a few devoted amateurs, feebly financed and publicly criticized. Their efforts have been documented in the society journal, which has had four name changes; *Bulletin of the American Interplanetary Society*, nos. 1–18; *Astronautics*, nos. 19–60; *Journal of the American Rocket Society*, nos. 61–86; and JET PROPULSION, nos. 87 to date; and in the writings (1, 2)[2] of Robert H. Goddard, one of the most technically competent of the early enthusiasts. It is interesting to note that in addition to a number of proposals[3] which are a source of tolerant amusement to present-day readers, many concepts were brought forward which later were found valuable although at the time there were insufficient means for testing them. Among these, for example, were the notion that a propellant's density impulse was a more significant parameter than its specific impulse; also the demonstration of the first regeneratively cooled motor.

The advent of World War II in 1941 resulted in immediate strong financial support for rocket research; the prolonged cold war following it has maintained this support to such a degree that rockets are today a billion-dollar industry. It is interesting to note the ways in which military requirements have directly influenced specific technical advances; the following list is typical:

1 Range

Need for increased range has led to low structural weights and high specific impulse. Pounds thrust per pound of combustion chamber has moved from less than 100 to over 200, while sea level specific impulse has typically increased from 200 sec to 250 sec.

2 Payload

Need for increased payload has led to larger thrust motors, substantially larger than the German V-2.

3 Accuracy

Need for increased ballistic accuracy has led to improved control of impulse delivered. The V-2 possessed range errors of 5 miles when its 60 sec thrust was terminated with an accuracy of $\pm 1/2$ sec.

[1] Research Staff. Mem. ARS.

[2] Numbers in parenthesis indicate References at end of paper.

[3] Such as the idea that nozzles were better without an expanding section (no. 49) and that propellants could be pressurized by means of a tube inserted in the exhaust jet (no. 34).

[4] A note in the October 1937, *Astronautics* states: "A good rule for rocket experimenters is this: always assume that it will explode!"

Fig. 1A Large-scale rocket engine on North American Aviation Company's static test stand near Los Angeles, California. The flame is nearly 50 ft long

Fig. 1B A3D aircraft take-off using a dozen 4.5 sec, 5000 lb thrust JATO units manufactured by Aerojet-General Corporation. Close-up view of a JATO unit of this type shown in Fig. 1B

4 Reliability

The use of JATO on manned aircraft has required a high degree of reliability in the operation of both solid and liquid rockets. Whereas 1930–1940 experimenters hid behind sandbags,[4] a present-day pilot wagers his life on the fact that a battery of several rockets will fire simultaneously with high reliability (see Fig. 1B).

5 Simplicity

The need for simple equipment which can be handled by troops has encouraged the development of solid motors for new applications.

The Pioneers

The vision and initiative of certain individuals in academic, military, and industrial circles were an indispensable ingredient to the success of the rocket program in the United States. The winning of World War II depended heavily upon the rapid development of unguided solid propellant rockets, which has been well documented (3) by J. E. Burchard. The unclassified aspects of more complicated rockets have been documented up to 1952 by G. P. Sutton (4), up to

1954 by British writer K. W. Gatland (5), and recently in *Interavia* (6).

The earliest group to appreciate the potentialities of rockets was the academic group. First among these, of course, was the legendary figure of Robert H. Goddard of Clark University. With modest (by present-day standards) assistance from the Guggenheim Foundation, he struggled virtually single-handed and in secrecy from 1919 to 1940 with problems which later proved difficult even for large and well-financed research teams. His patents and writings (1) show great fertility and ingenuity. Next among the university workers were Theodore von Kármán and his protégés at California Institute of Technology. As early as 1937 his students, including H. S. Tsien (later to become Guggenheim Professor of Jet Propulsion at CalTech), Frank J. Malina (later acting director of the Jet Propulsion Laboratory at C.I.T.), and Martin Summerfield (later editor of the national journal of the ARS and professor of jet propulsion at Princeton) did both analytical (7) and experimental (8) work on rockets (see Fig. 2). The Jet Propulsion Laboratory at California Institute of Technology was destined to become the first major rocket laboratory and was sponsored jointly by Army Ordnance and the Air Force. Its present strength is over 1000 employees (see Fig. 3), although it originally began as a single tin shack (the "gashouse")—see Fig. 4—in which gaseous oxygen and hydrogen were burned in one small rocket.

At the same time that JPL was getting started, C. C. Lauritsen, California Institute of Technology physicist, was urging the National Defense Research Council (NDRC) to work on tactical short-range solid propellant rockets. This action resulted, among others, in a Navy-sponsored crash program (sometimes called the "Eaton Canyon Project") administered by CalTech and ultimately growing into the Naval Ordnance Test Station (NOTS) at Inyokern, Calif., under the direction of L. T. E. Thompson. Other branches of the NDRC program resulted in a joint effort by George Washington University and the Alleghany Ballistics Laboratory in which C. N. Hickman, W. H. Avery, R. E. Gibson, and A. Africano played prominent parts.

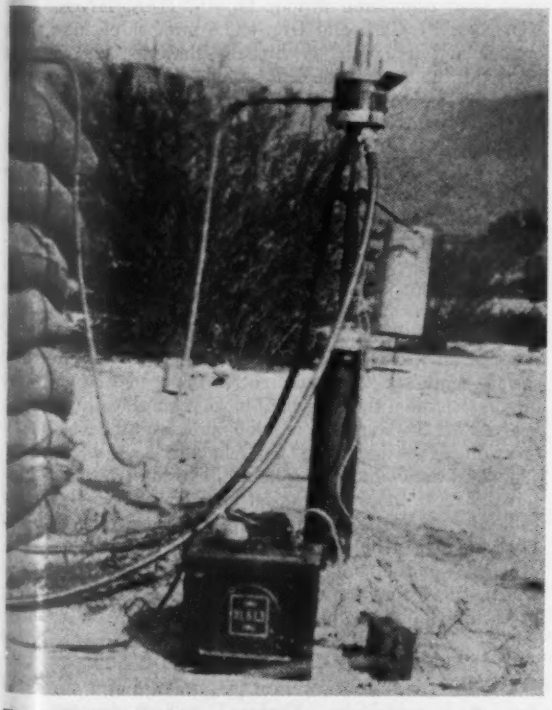


Fig. 2 Early static test stand using gaseous oxygen and liquid alcohol. Operated in 1937 on California Institute of Technology campus

Fig. 3 Air view of the CalTech Jet Propulsion Laboratory taken in 1954

Fig. 4 Bird's-eye view of the CalTech Jet Propulsion Laboratory (then known as the GALCIT project) in 1942

Among early industrial groups to interest themselves in rockets was the Aerojet Corporation, under the presidency of Andrew G. Haley (later to become National President of the ARS) whose principal engineers were Chandler C. Ross and Robert Young. Another business group was Reaction Motors, Inc., under the presidency of Lovell Lawrence. This company employed many of the charter members of the original ARS, including John Shesta, J. H. Wyld, and Roy Healy. In addition to these two companies, who specialized in rocket motors and might be called "power plant" companies, several large existing business organizations became interested in rockets and early acquired competence in the field. Among these were North American Aviation (through its Aerophysics Laboratory), the General Electric Company, the M. W. Kellogg Company, the Glenn L. Martin Company, and Curtiss-Wright Corporation.

Key men coordinating all this academic and industrial activity were the military men on whose shoulders rested the burden of deciding among various competing technical proposals and disbursing the large amounts of money which were needed. Among officers who, in these early days, carried heavy responsibility were the following: For the Army Ordnance, Col. L. A. Skinner (whose initiative and enthusiasm led him to work on his own time on experiments leading to the Bazooka); Col. G. W. Trichel; and Col. (now General) L. E. Simon. For the Air Force, General D. L. Putt, Col. E. N. Hall, and civilian Weldon Worth. For the Navy,

Admiral C. M. Bolster and Commander Robert E. Truax assisted by civilian Milton W. Rosen, who administered the development of the Viking (9) research rocket in behalf of the Naval Research Laboratory.

Another group of men who entered the American scene late but who nevertheless have contributed significantly to rocket progress in the United States are the German rocket specialists who emigrated to this country in 1945. These include Walter Dornberger and Wernher von Braun of the well-known V-2 project (10).

In the following discussion of progress in rocket power plants, it will be appropriate to give predominantly broad and qualitative information (65, 66) since neither the best interest of national security, the space available, nor the capacity of the reader's memory would recommend a large amount of detail.

B Propellants

1 Basic Requirements

The prime requirement of a rocket propellant is high impulse per unit volume. Beyond this, a good propellant also conforms to many specifications; stable combustion at pressures of a few hundred psia, ease of ignition, products of combustion of low molecular weight, good storage and handling properties, and low cost. In the past twenty-five years only a handful of oxidizers, perhaps half a dozen, and a somewhat larger number of fuels have been found generally acceptable. Taking together solids and liquids, perhaps a hundred reactions have received major attention (11–16). Of these, the liquids involving liquid oxygen or nitric acid have been developed to the point of becoming "work-horse" propellants, and the solid propellants containing nitrates and perchlorates of potassium (smoky) and ammonia (smokeless) have similarly been widely used. A large number of properties of each propellant component must be known, such as density, vapor pressure, melting, boiling and freezing points, viscosity, and modulus of elasticity. The measurement of these has been and continues to be a major research activity. Fuel standardization such as characterizes automobile engines has not and may never be achieved.

2 Influence of Propellant on Design

The great variety of rocket propellants has brought as a consequence a large number of engine designs, since the propellant has a profound influence on design. For example, the design of pumps to handle liquid propellants depends on the vapor pressure, density, and optimum combustion pressure of the particular fluids; the combustion chamber dimensions depend on the required combustion time (L^*). The motor cooling technique depends upon boiling point, heat capacity (17), and thermal stability. The degree of atomization and mixing provided by the injector must be adjusted to the needs of the propellant. Even the proper proportioning of the nozzle depends upon a knowledge of the ratio of specific heats (18, 19) of the combustion products.

In the case of solid propellants the interaction of properties with mechanical design is even tighter (20). A propellant with a low burning rate, for example, requires a large surface, thus influencing grain configuration. A propellant with low yield strength cannot be used in situations which require substantial elastic deformation of the grain.

3 Gaseous, Liquid, and Solid Propellants

Gaseous propellants have never been considered seriously for rockets because of their low density, although they are useful for combustion studies (8). The competition between solid and liquid propellants, however, has been vigorous for twenty-five years (11), and still goes on. A brief list of their respective advantages is given:

Virtues of Liquid Propellants. (a) *Specific Impulse*—Up to 25% higher than that of good solid propellants. (b) *Controllability*—Started spontaneously if desired, throttleable over limited ranges, and easily cut off by valve action. (c) *Operating Pressure*—May be contained in a low-pressure, lightweight vessel and pump-fed into a high pressure combustion chamber, whereas all of a solid propellant must be contained at combustion pressure. (In principle a cartridge injection scheme would circumvent this, but it has never been developed.) (d) *Duration*—Liquid propellants provide great flexibility in burning time, whereas limits are set upon solids by available burning rate and web thickness. (e) *Heat Transfer*—Liquids may be used regeneratively for cooling. The absence of this inherent advantage limits duration of solid nozzle operations.

Virtues of Solid Propellants. (a) *Handling and Storage*—There are no problems of corrosion, toxicity, or volatility, as in the case of liquids. This is a strong military advantage. (b) *Simplicity and Reliability*—There are no pumps, turbines, valves, or gas generators in solids engines. This simplicity carries with it reliability. (c) *Storage and Readiness*—There is no last-minute filling of tanks or necessity for long-time storage of low-temperature fluids. (d) *Density*—Densities are 15–25 per cent greater than typical liquids. This is an advantage tending to offset the greater specific impulse of liquids, particularly in high-efficiency missile designs. (e) *Divisibility*—Solid propulsors can be conveniently designed in unit packages and grouped in bundles, while still maintaining efficient operation. This makes for flexibility in design, since it is not necessary to create a unique engine for each application.

4 Progress with Liquid Propellants

The great variety of oxidizers, fuels, and monopropellants which have been examined in recent years is reminiscent of the large number of spirituous beverages available in the stores. The profusion of flavors is confusing, but the fundamental ingredients and effects are the same for all. Oxidizers which have been considered include O_2, O_3, H_2O_2, HNO_3, N_2O_4, NO, N_2O, F_2, ClF_3, and OF_2. The number of fuels, both organic and inorganic, is virtually limitless, and includes nearly all the oxygen-deficient organic chemicals such as the saturated and unsaturated hydrocarbons, alcohols, ethers, ketones, amines, nitroparaffins, and aromatic compounds. Also, important inorganic fuels include H_2, NH_3, N_2H_4, and some of the low atomic weight metals either pure or in the form of hydrides or amines.

It would be impossible to quote the voluminous information on properties and performance of even those combinations which have been experimentally tested. A substantial amount of data is available in the literature (11–16). The general plan of propellant research has been to determine substances of possible interest, measure or calculate their physical and chemical properties (17–19), compute their specific impulses (13), and check them in actual rocket motors. Even if the propellant looks promising at this stage, it is only at the beginning of a long program to develop for it an engine of the desired size and reliability.

Typical data which must be acquired are ignition characteristics (20B, 21), heat transfer behavior (22), additives for catalysis, control of freezing point, corrosion, or decomposition, and logistic information on cost and availability. Idiosyncrasies of the combustion process may cause vibrations which will disrupt the engine (29–32). The mere handling of certain liquids would present difficulties; for example, fluorine, which will burn with metals, glass, concrete, and even water.

Table 1 gives the theoretical performance of a number of "standard" propellants. Engines have been operated for all these which will produce over 95 per cent of the calculated performance.

Table 1

	Mixt. ratio R, oxid/fuel	Char. velocity c^*, ft/sec	Combustion temp. T_c, ° F
LOX[a]—Alcohol (75%)	1.3	5537	5079
LOX—Gasoline	2.5	5540	5470
LOX—Hydrazine	0.33	5610	3632
LOX—Ammonia	1.4	5840	4951
LOX—Hydrogen	3.0	8345	4290
RFNA[b]—Aniline	3.0	5015	5065
H_2O_2—Nitromethane	0.5	5313	4687
H_2O_2 (87%)	...	2940	1216
Nitromethane	...	5020	3950

[a] LOX = Liquid oxygen.
[b] RFNA = Red fuming nitric acid.

Table 3 Typical[a] Solid Propellants

Double Base	
Nitrocellulose	52%
Nitroglycerin	43%
Additives	5%
Asphalt Base	
Potassium perchlorate	76%
Asphalt	17%
Oil (SAE No. 10)	7%
Rubber Base	
Potassium perchlorate	73%
Polymer fuel	27%

[a] These compositions are approximate only, and do not include certain minor constituents needed for processing.

5 *Progress with Solid Propellants*

As in the case of liquid propellants, there are relatively few oxidizers, but many fuels available to combine into solid propellants. In order to be in the solid state, oxidizers necessarily combine inert atoms with oxygen, and frequently are in the form of hygroscopic crystals with poor mechanical properties; for example, potassium and ammonium perchlorates and nitrates. The weight per cent of available oxygen in four common oxidizers is shown in Table 2.

Table 2

Oxidizer	Wt. % O_2 available
Potassium perchlorate	46.0%
Ammonium perchlorate	34.0%
Potassium nitrate	39.5%
Ammonium nitrate	20.0%

As a consequence of the relatively low fraction of available oxygen illustrated in Table 2, a high performance propellant, in which the amount of available oxygen is nearly stoichiometric, consists of a small fraction of fuel (25 per cent or less) loaded with a large amount of oxidizers. This situation engenders physical problems, the solution of which comprises a large fraction of solid propellant development in the last decade.

The fuels which have been developed are drawn from the hydrocarbon polymers—the waxes, plastics, and rubbers—and must be capable of remaining fluid while being mixed with the oxidizers, then hardening or polymerizing into an elastic solid with rather rigidly prescribed physical properties. One of the well-known early propellants, the GALCIT asphalt-base type, was made by melting asphalt and incorporating the oxidizer in a mixer. Its formulation is given in Table 3. One of its difficulties was that it softened when stored at high temperatures, and indeed on certain occasions poured out the nozzle.

The physical properties of a good solid propellant include the following: (a) *Tensile Strength*—High tensile strength is needed to prevent deformation of the charge under operating pressures and accelerations. These deformations would, for example, change the areas of flow passages and hence operating conditions. (b) *Elongation*—High per cent elongation (ability to deform elastically and return to original dimensions) is valuable for charges which are necessarily deformed by pressure. It prevents cracking with consequent dangerous increase in burning area. (c) *Adhesion*—In case-bonded designs, the charge must follow expansions and contractions of the chamber without breaking the bond between them. (d) *Fluidity*—Most propellants are cast into a chamber, and hence must have low enough viscosity to flow even when heavily loaded with oxidizer particles. To retain fluidity with a relatively small amount of liquid requires that particle size distribution of the oxidizer be carefully controlled.

In addition to prescribed physical properties, certain ballistic properties of a solid propellant are important, namely: (a) *Burning Rate*—This is a sensitive function of particle size, pressure, opacity, and catalysts, and should be adjustable from 0.01 in./sec to 10.0 in./sec to fit specific applications. It is particularly desirable to have the burning rate as insensitive as possible to combustion pressure. (b) *Sensitivity*—The temperature and pressure conditions which must be supplied by an igniter in order to achieve prompt and reliable combustion must lie between the hazardous state of too-easy combustibility and an equally hazardous sluggishness which would tend to produce hang-fire. (c) *Smoke*—Other things being equal, propellants which have no metal atoms and hence can be smokeless are preferred. (d) *Molecular Weight*—For the same reaction temperature, substances producing combustion products of low molecular weight give higher performance. This favors compounds which have a high per cent of hydrogen and nitrogen over those containing high percentages of carbon.

Many of the resources of the vigorous plastics industry and the science of rheology have been brought to bear upon improving and controlling the properties just listed, with considerable success. Solid propellants have improved in specific impulse from 180 sec (1940) to over 220 sec. Their detail specifications and formulations are but scantily documented, as much of their preparation is proprietary art. However, there exists some literature on solid propellants (32–40).

6 *Nuclear Powered Propulsion*

Although nuclear energy has been known since 1945, and the existence of a nuclear-powered submarine was made public in 1954, there is as yet no evidence of nuclear energy sources being applied to rockets. This does not mean that there is lack of interest in or appreciation of the possibility. There have been speculations as early as 1948 both in the United States (41–44) and Britain (45) as to the advantages which might accrue by the use of fissionable materials.

The principal drawback at present to the use of nuclear power is the inability to take full advantage of the available temperatures. The specific impulse attainable with even the lowest molecular weight working fluid (hydrogen) is not more than 3 or 4 times that of the most energetic chemical reaction, owing primarily to the lack of a material from which to build a heat exchanger between the reactor and the expendable working fluid. The nuclear rocket will really come into its own only by some bold invention which accomplishes the tremendous heat exchange required and at the same time conserves fissionable material without the necessity for a conventional solid-boundary heat exchanger.

C Liquid Rocket Engines

Introduction

As is typical of a new field of engineering, the nomenclature has not quite settled down. In particular, the system which produces a reaction force is known variously as a propulsor, thrust cylinder or chamber, reaction motor, jet engine, rocket power plant, rocket engine, or simply rocket. We shall define a rocket "engine" as the system comprising tanks, pressurization means, valves, and "motor." Let us examine the trends in the various components of this system over the past twenty-five years, proceeding downstream from the propellant tanks and considering each subassembly in turn.

Feed System

The struggle for ever lighter weights has placed particular demand upon tank designers, since they are responsible for one of the largest single components of the engine. It has been necessary to reduce safety factors to an absolute minimum. Since a safety factor is a number introduced to compensate for lack of knowledge of structure or environment, one way to reduce this factor without introducing additional hazard has been to dispel some of the ignorance by rigid quality control (welds, sheet gages, etc.) and extensive environmental testing (vibrating, pressure and temperature cycling, etc.). By this means, "safety" factors can be reduced to the point where tanks are designed to operate at 80 per cent of their bursting pressure. The use of newer alloys, heat treatments, and close design has made it possible to design solid propellant containers (which operate at many hundreds of psia) which weigh less than 15 per cent of the propellant they contain, contrasted with 100 per cent (or more) typical of early artillery rockets.

In the case of those liquid tanks which require only the pressure necessary to provide suction head to propellant pumps, tanks can be built which weigh an even lower (or less than 10) per cent of the weight of the contained fluid. Various special problems of tanks, such as the effect of "sloshing" on the dynamics of a vehicle and techniques for completely emptying a maneuvering tank by means of bags or pistons have received attention.

The supply of fluid pressurizing gases, whether for pump suction or rocket injection, presents weight reduction problems. In some of the older vehicles which use tanked compressed gases, this high pressure tank and its contents are over 10 per cent of the take-off weight. A good means of reducing this excess weight is to generate the gases chemically (see Fig. 5) as they are needed, thus avoiding the weight of a large high-pressure gas container. This can be done by the use of solid propellant cartridges, monopropellants decomposed catalytically (as was H_2O_2 in the V-2) or bipropellant reactions diluted either by an excess of one propellant component or by a third fluid such as water. The dilution is often necessary because the combustion products must be kept cool enough to apply over propellants or use against turbine blades. The use of gas generators presents many difficulties of techniques as well as of understanding of the reaction kinetics involved, and the present state of the art cannot be considered more than well begun.

Fig. 5 Exploded view of a chemical generator for propellant pressurizing gases. Note catalyst in pellet form

The advent of large rockets stimulated the venerable art of pump design by providing a need for lightweight, high speed, low suction pumps with very large flow rates. The V-2 pumps operated at 3800 rpm, suction specific speed of 8000, and discharge head of 300 psia for a flow of approximately 300 lb/sec. Pumps of a more recent vintage have been able to handle similar flows at several times the discharge head, for about half the dry weight of metal parts.

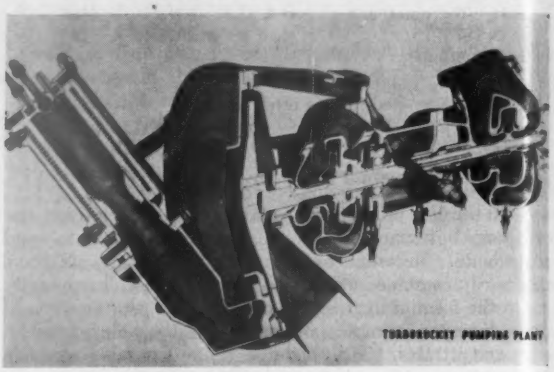


Fig. 6 Early turbopump for acid and aniline developed at the CalTech Jet Propulsion Laboratory

Unusual fluids such as liquid oxygen and nitric acid presented seal and bearing problems, which were solved for durations of operations of a few hours, a condition quite acceptable where the normal operating time is measured in minutes. An early acid-aniline turbopump assembly developed at JPL is illustrated in Fig. 6.

Propellant Injectors

Perhaps the most mysterious and empirically designed component of a thrust chamber remains the injector head, even after decades of experience (46–50). Once a workable design is found, experimeters tend to cling to it with only minor modifications, like the distillers of rare old Benedictine guarding their proprietary recipe. The number of ways in which one or two liquids may be injected into a chamber in order to be mixed and atomized is very large. We may sort these ways out after a fashion by considering the geometry and dynamics of the flow, respectively.

(a) *Flow Geometry*

Typical injector stream cross sections may be cylindrical, annular, conical, flat (this last either by impingement or extrusion), or some other shape. Streams may be combined in pairs or triplets or other multiples at any orientation and allowed to impinge at any point in combustion space. The relative diameters of streams may have any value, though there is evidence (49) that, if they match, better mixing is secured. Fig. 7 shows schematically some geometries which have been found workable.

A given configuration of mixing and atomizing streams may be repeated periodically over the face of the injector, and many large-scale injectors, for example the V-2, have been designed in this manner. Certain configurations have no definite impingement point (the "showerhead" injector); these are particularly adaptable to volatile propellants such as liquid oxygen. One scheme for classifying injectors considers the unit mixing configuration to repeat itself to infinity (47) so as to provide a one-dimensional character to the flow.

(b) *Flow Dynamics*

Significant dynamical variables describing an injected stream are its average velocity, momentum, and its velocity

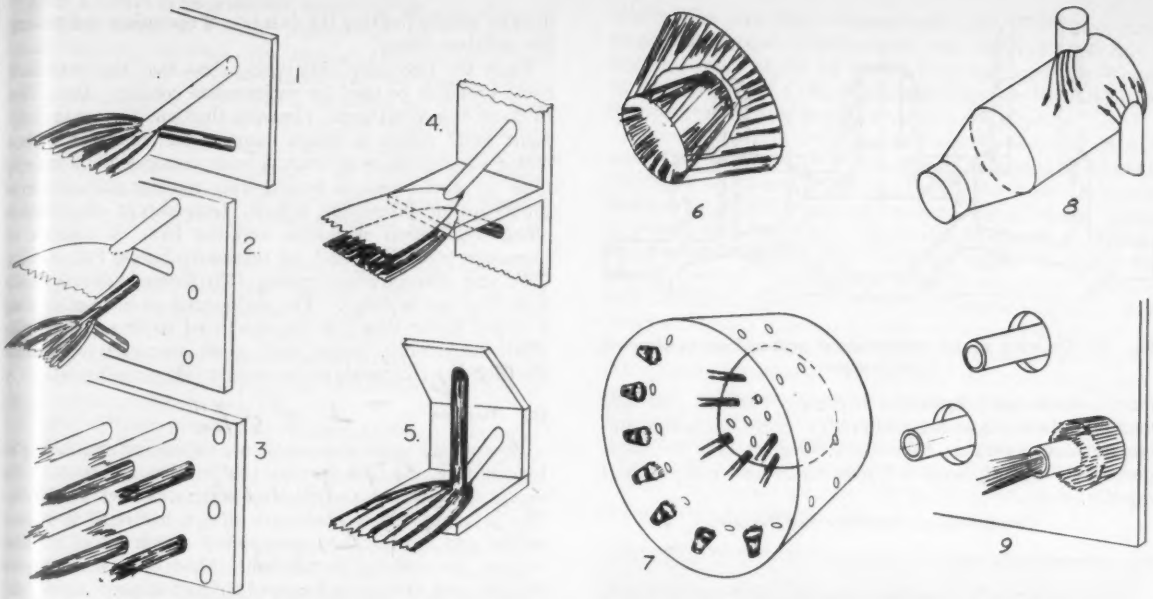


Fig. 7 Configurations of fluid jets used in liquid propellant injector heads. (1) Unlike impinging. (2) Like-on-like impinging. (3) Nonimpinging (showerhead). (4) Splash plate. (5) Mix plate (Enzian). (6) Converging-diverging cones. (7) Intersecting cones and jets (V-2 Rosette) with O_2 in center. (8) Premix. (9) Coaxial

profile. When streams are combined, important parameters are the degree of mixing, degree of atomization (particle size distribution), and spatial distribution of particles. Rather careful measurements (49) of these quantities have been made for flow in the absence of combustion. How these results are affected by the thermal and pressure disturbances of combustion is not well understood, although efforts have been made to evaluate the relative importance of mixing and atomization during actual firing tests. These results show that mixing and atomization must both be present for efficient hydrocarbon-liquid oxygen reaction; see Fig. 8.

A few cases have arisen in which the injector was rotated during operation (spin-rockets). Under rotation, Coriolis effects (51) tend to cause misimpingement and poor injector performance unless special designs are used; see Fig. 9.

Two recent concepts which have shown promise in injector design are: (a) stabilizing the liquid mixing process and decoupling it from disturbance by gas pressure waves by allowing jets to impinge on a solid surface rather than on each other, thus reducing pressure fluctuation and combustion instability; and (b) burning a minor fraction of the propellants and using the resulting hot gases as an atmosphere into which the remaining major fraction is injected, thus speeding up

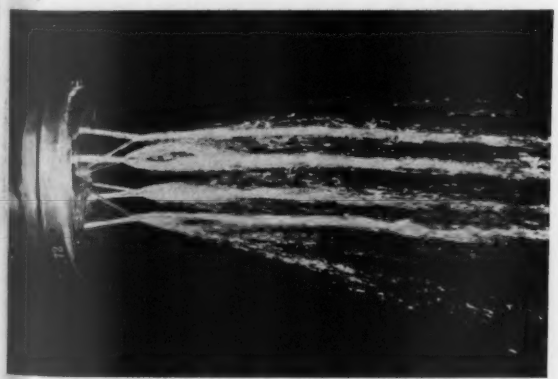


Fig. 8 Water test on liquid propellant injector to check impingement of fuel and oxidizer streams

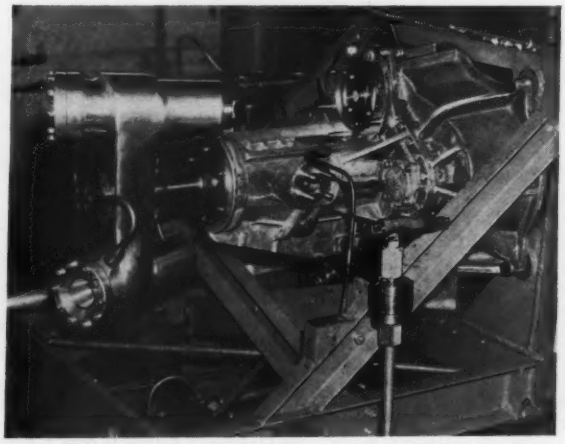


Fig. 9 A type of rocket engine (the Aerotojet) in which a "pinwheel" arrangement of thrust cylinders provides pumping torque

vaporization and improving both performance and stability (two-stage injector).

It has long been known that heat transfer to chamber walls is a sensitive function of injector design. Since only 1 or 2 per cent of the total fuel energy flows through the walls, it is relatively easy to increase this heat flux severalfold (to an unacceptable value) by small changes in injector geometry. In large-scale injectors, there is some flexibility of design, permitting concentration of unburned and hence cooler fuel along the walls. In small scale injectors, it is desirable to keep the net momentum of the reacting mixture nearly axial in direction for minimum heat transfer. Knowledge of phenomena near the injector is still sketchy.

(c) *Mechanical Design*

Injectors have been cast, machined and welded, stamped, and assembled from bundles of tubing brazed together. Their principal requirement is to provide manifolds for fuel and oxidizer which cannot possibly interleak, yet which allow close spacing of the orifices. At the same time, the orifices

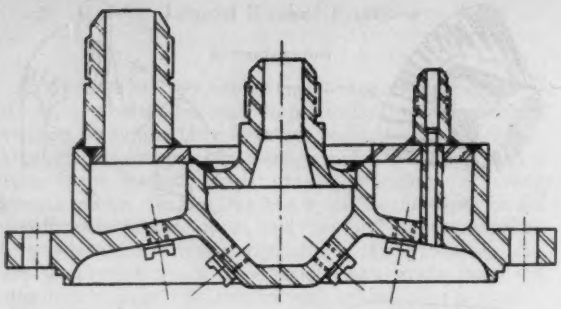


Fig. 10 Drawing of an experimental acid-aniline injector of 1000 lb scale

must possess good upstream hydraulic contour (49) and maintain their alignment accurately. Some ingenious and labyrinthine manifolds have been designed (47) for these purposes. Fig. 10 shows a typical small-scale experimental injector.

Combustion Chamber and Nozzle

(a) *Chamber Design*

Early versions of combustion chambers were built of heavy steel as if they were to undergo violent pressure peaks, as indeed they often did. Nozzles, which were made of massive copper blocks, were obliged to be "heat sinks," since fluid cooling was not yet perfected. An early (circa 1942) experimental motor of this type is shown in Fig. 11.

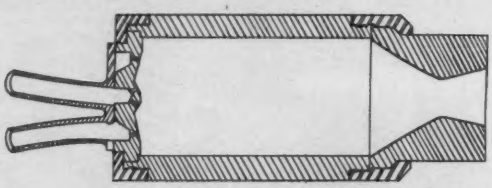


Fig. 11 Experimental motor of uncooled type suitable for about 20 sec operation at 200 lb thrust

The trend in chamber development has been toward higher chamber pressures and lighter weight. Most liquid rockets will not burn well under 100 psia; the V-2 operated at 225 psia. Current rockets operate at 300 psia and higher. Reduction in weight has been accomplished by removing heat through regenerative fuel cooling and thus operating the chamber envelope at low temperatures where it can retain full strength, see Fig. 12.

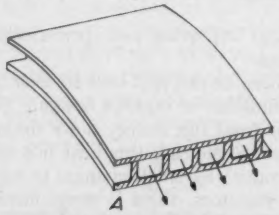


Fig. 12 Scheme for conducting heat away from rocket combustion chamber wall: (a) helical flow in ducts machined in chamber wall

(b) *Heat Transfer*

Rocket temperatures and rates of heat transfer lie well outside the range of standard engineering data. The first problem to be faced in combustion chamber development was to operate motors made of conventional structural materials with gas temperatures of 5000 F and heat flux values of 2 to 20 Btu/in.^{2} sec into the walls. It was solved in the early days by simply limiting the duration of operation and making the structure bulky.

From the beginning (53) it was clear that the propellant could probably be used for regenerative cooling. Its ability to do so was so marginal, however, that small errors in judgment could render a design inoperative. In order to put motor cooling design on a sound basis, considerable work was done on such topics as boiling heat transfer (22), physical properties of propellant liquids, temperature distribution along combustion chambers, and the like. A number of ingenious techniques such as refractory liners, film cooling (54), and transpiration cooling (55) through porous walls were explored in detail. The engineering problem of cooling a rocket motor may now be considered to be satisfactorily, albeit empirically, solved until more energetic propellants are tried (see comments under nuclear (44) propellants).

(c) *Nozzles*

Because the gases in a nozzle are expanding and falling in temperature, the heat transfer problem has not been severe except at the throat, and even here has not proved intractable. The principal concern in nozzle design has been to reduce weight and provide the most efficient conversion of random motion into ordered momentum. Most early nozzles were simple cones with the exit cone of 15° half-angle. As vehicles have been flying higher at lower pressures, there has arisen a need to examine the behavior of "overexpanded" nozzles; i.e., nozzles which are correctly expanded for low pressures but which may experience flow separation at sea level. Some work (56–57) has been done on separation and also on the design of nozzle contours other than simple cones.

(d) *Ignition and Control*

The writer recalls driving up to the Jet Propulsion Laboratory one day in 1943 and, just after stepping out of his car, hearing a loud report from a test stand about 100 yards away followed by the thud of a 15 lb copper nozzle landing at his feet. Such incidents, euphemistically labeled "hard starts," typify early liquid rocket ignition problems. The rapid ignition of two reacting fluids entering a chamber at high flow rates is a complex transient phenomenon (20B, 50), sensitive to the relative entry time and flow rates of the two components, to chamber wall temperatures, chamber volume, and many other factors. The starting technique employed in 1943 was to begin with strongly reduced flow until combustion was well established, then open up the valves to full flow. This same technique was followed in the V-2 launchings, with the operator judging by the appearance of the flame when to go from partial to full thrust.

Such subjective decisions are hardly satisfactory, however, for a large scale rocket in which a few seconds flow may represent tons of propellant. Progress has been made in the automation of the critical seconds of the initiation of combustion, but much remains to be done. Fig. 13 shows some of elaborate plumbing required by a modern rocket control.

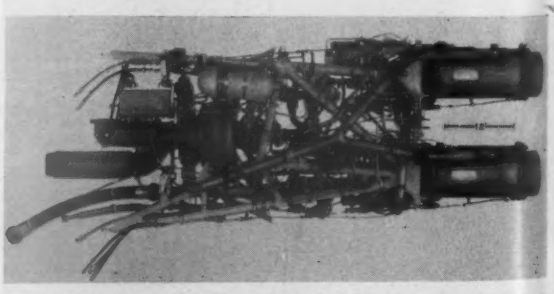


Fig. 13 Liquid rocket engine for use on manned aircraft, showing elaborate development of control system (Aerojet YLR45-AJ-1 type)

After a rocket is once started, control of the magnitude of the thrust would be a useful feature (58, 59). Nearly all rocket engines, however, are used at approximately fixed thrust. There are two convenient ways to change thrust; by changing either combustion pressure or throat area. Reduction of p_e also reduces efficiency and is not an attractive method. Adjustment of throat area is thermodynamically efficient but mechanically difficult. As a result, adjustment of impulse is usually accomplished by adding and subtracting chambers or by controlling time of shutoff rather than by throttling.

Control of the sound level of a rocket motor has never been seriously attempted, although everyone agrees that rockets are among the world's noisiest devices. A typical rocket releases 10^5 hp of energy. If only one-thousandth of 1 per cent of this energy were to be converted to sound, this would be 80 watts of acoustic energy, or several times the output of a large public address system.

Control of thrust orientation (60) is a necessary feature of any vehicle which does not have substantial aerodynamic forces at its disposal. This need does not arise for low-altitude applications such as jet-assisted take-off and boosted or aircraft-launched missiles. However, with the V-2 and similar vehicles, it was necessary to develop jet vanes (62), auxiliary jets, or gimbals for the combustion chamber. The Viking research rocket, for example, uses both auxiliary jets (for roll control) and gimbals (for pitch and yaw control). Fig. 14 shows the Viking gimbals schematically.

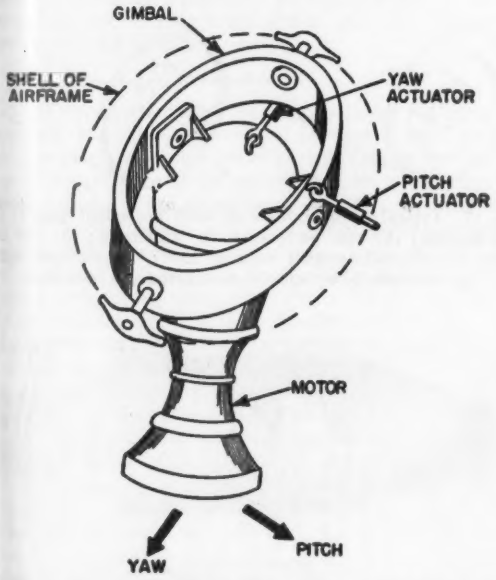


Fig. 14 Schematic diagram of gimbal system used for orienting thrust in Viking research rocket

Since the magnitude of thrust is not readily adjustable during flight, it is doubly important that its duration be controlled accurately. This implies that techniques be developed for cutting off the flow of propellants precisely. A typical ballistic device will decrease range 75 per cent merely by decreasing thrust duration 25 per cent. A rocket accelerating at several g's will increase velocity by 100 ft/sec during the second of flight. Shutoff and control problems of this type have received increasing attention during the last decade. They tend to be uniquely defined by the motor application.

Contemporary Engines

We shall conclude the discussion of liquid rockets by mentioning some of those end-products about which some public information has been released (61, 62). The two most prominent German developments were the V-2 (A-4) liquid oxygen-alcohol engine of 56,000 lb thrust, and the Walter hydrogen-peroxide C-Stoff (alcohol-hydrazine hydrate) 4000 lb thrust engine used to propel the ME-163 airplane.

Among American developments are the Bell X-1 experimental aircraft propulsor using liquid oxygen and alcohol, developed by Reaction Motors, Inc.; the Naval Research Laboratory Viking research rocket engine using liquid oxygen-alcohol engines developed also by Reaction Motors; the Aerobee sounding rocket with an engine developed by Aerojet-General Corp.; the Nike ground-to-air missile with sustainer developed by Bell Telephone Company and Douglas Aircraft Company; and the Corporal ground-to-ground missile developed by the Jet Propulsion Laboratory of California Institute of Technology. An interesting application of a large-scale rocket engine developed by North American Aviation Company has been made to a supersonic sled test vehicle, illustrated in Fig. 15. Liquid engines having a high degree of controllability and safety have been developed for jet-assisted take-off by Aerojet-General Corp. One of these is illustrated in Fig. 16.

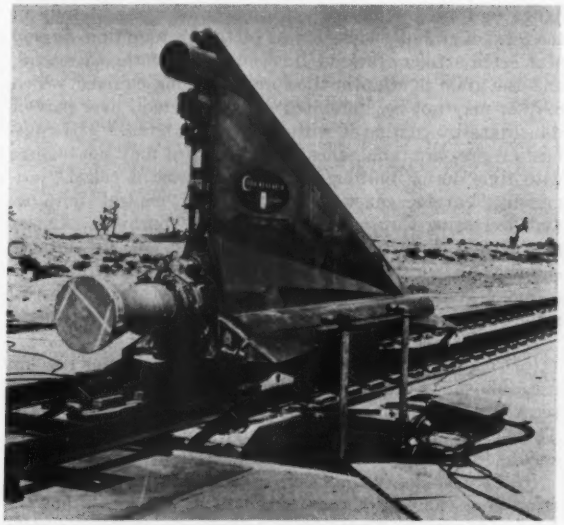


Fig. 15 50,000 lb thrust engine built by North American Aviation to accelerate test sled to 1500 mph at Wright Air Development Center

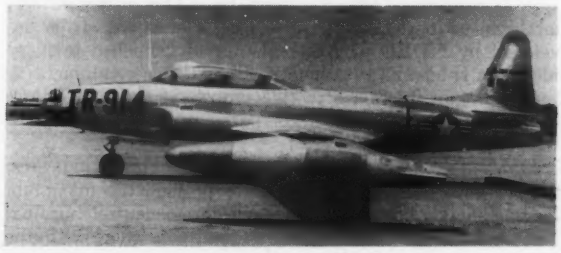


Fig. 16 F-800 airplane with Aerojet AJ10-15 jettisonable wing-tip rocket for ATO or superperformance. Rocket is 1000 lb thrust, has 3.5 min duration, and can be restarted at will

There is a constant effort to improve the reliability (63) of all these rocket engines, and present-day practice insists that they be "practical" devices, with extensive environmental tests at high and low temperatures, leak tests, pressure tests, flow and vibration tests, calibration tests, hardware weight limits, ability to withstand aerodynamic loads and repeated operations of the control systems, interchangeable spare parts, convenient means for fueling, minimum use of

critical materials, specified thrust and impulse tolerances, and all the other restrictions similar to those imposed on aircraft, automobiles, or any other widely accepted motive power plant.

D Solid Rocket Engines

In the friendly rivalry which has long existed between solid and liquid rockets, solid propellants have the distinction of having been exclusively used in historical times: by Congreve for the English, in the American Revolution, and in World War II. They have carved out a secure niche in modern times as the motive power for short-range unguided high-caliber artillery, both air-launched and ground-launched. Their technology has been described in at least two (33, 34) unclassified textbooks. Liquid rockets have held the lead as motive power for large-scale, long-range applications, but even here new developments in solid rockets indicate that this supremacy may be challenged.

1 Grain Design

The shape of the solid charge or "grain" (an etymological hangover from the days when black powder was literally in the form of grains) is determined by the burning time desired of it. For artillery rockets, this is usually less than a second, and the grain is often in the form of a long cylinder which may or may not be "inhibited" or "restricted" over part of its surface by coating it with an inert material. The combustion pressure (and hence thrust) may or may not change with time during burning: increasing thrust is called "progressive" burning, constant thrust is called "neutral" burning, and decreasing thrust called "regressive" burning. Almost any desired characteristic can be obtained (20) by suitably shaping and/or restricting the grain. Many geometrical forms of grain have been tested in recent years; a chart of some common ones is given in Fig. 17.

A few of these configurations merit comment:

(a) *Cigarette burning*—(Fig. 17, part A). For assisted take-off use, this shape provides the desired long duration of 10–20 sec with a propellant whose burning rate is about 1 in. per sec. This burning rate was typical of early propellant formulations such as the asphalt-based GALCIT propellant.

(b) *Case-bonded internal star*—(Fig. 17, part B). This configuration, one of the more recent to be developed, has the triple advantage of providing strong support for the grain without bulky and vulnerable traps, protecting the case walls against heat flow, and burning with a nearly neutral characteristic.

(c) *Cruciform*—(Fig. 17, part C). This configuration, inhibited on part of its surface, was a standard shape developed by NDRC in 1942–1945 for air-launched artillery rockets. It has the advantage of filling the case volume with the maximum fraction of active propellant (loading factor) while retaining relatively large "port" area for the escape of the generated gases.

Many other grain shapes are possible, as Fig. 17 indicates. Nearly all of them are designed to provide the maximum loading factor, adequate initial port area, neutral burning, and to have a specified burning time consistent with the burning rates of available propellants.

2 Case Design

One important aspect of the intricate problem of solid design has been the choice of optimum case shape. A cylinder with hemispherical or ellipsoidal ends is usually chosen, with a length-to-diameter ratio chosen to balance between low aerodynamic drag, which favors a long slender tube, and ample port area for combustion gases, which favors a smaller aspect ratio (37). The case shape is also affected by web thickness (burning distance) of the grain, which in turn is determined by the total impulse, burning time, and

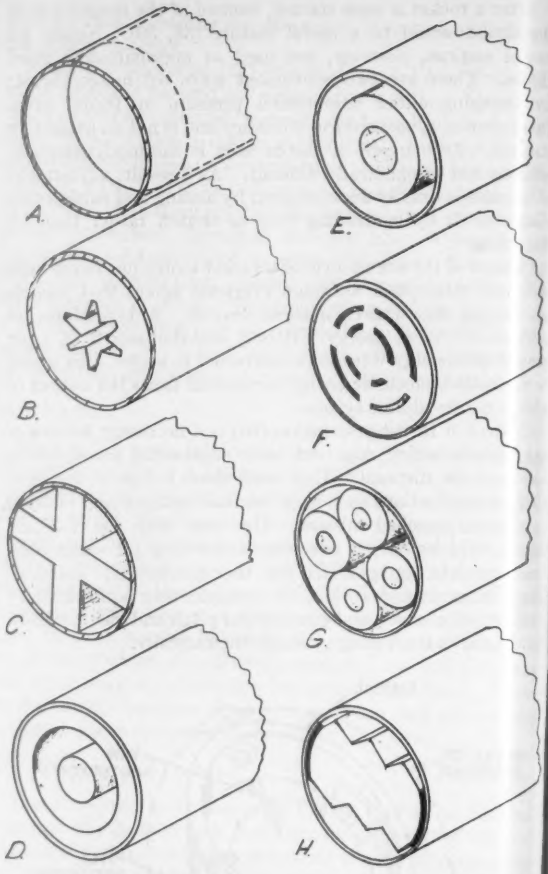


Fig. 17 Typical configurations of solid propellant grains: (a) end-burning; (b) star perforated; (c) cruciform; (d) rod and tube; (e) internal-external burning tube; (f) multiperforate; (g) multiple-tube; and (h) corrugated and restricted

Fig. 18 Applications of solid propellant rockets to jet assisted take-off showing effect of duration on aspect ratio: (Top) 15 sec 1000 lb JATO unit; (bottom) 2.2 sec, 33,000 lb; JATO u (Aerojet-General Corporation)

burning rate of the propellant (68). Two recent designs of sol propellant case with extremes of aspect ratio due to co trasting aerodynamic and impulse requirements are shown Fig. 18.

3 *Nozzles*

Short-duration artillery rockets may have their nozzles built of convenient materials such as steel. Longer-duration solid rockets, having no convenient liquid coolant available, ordinarily use refractory materials such as graphite or molybdenum in the critical throat region. As performance (i.e., temperature) and duration both increase, the cooling of solid nozzles may present new problems; as yet it has not.

In the absence of liquid coolant, some attention is being given to insulation of metal surfaces by various refractory, low-conductivity coatings, thus permitting the use of thinner walls. This technique would be of value, for example, both in lightening nozzles and in protecting outer casings against aerodynamic heating which might ignite the propellant.

4 *Ignition and Termination*

The initiation of combustion is only slightly simpler for solid rockets than for liquids. The design of pyrotechnic devices to bring the whole surface of a charge up to its ignition temperature, and to create a pressure under which combustion will be sustained, remains an art. Ignition must be done in a reproducible short time, and must not involve pressures high enough to damage the grain. The problem has been solved satisfactorily for artillery rockets (33) and, in spite of the apparent alchemy involved, does not appear to be a major problem of technique.

Terminating thrust of a solid rocket on command following ignition, is a rather more difficult problem than igniting it. To date this remains a relatively unexplored field. When it is successfully solved (64), a number of new applications will open up for solid rockets.

5 *Performance and Reliability*

It was recognized, as time went on, that since container and propellant were always associated together in solid motors, that the most valid measure of performance is the over-all impulse-weight ratio of the propulsive unit rather than the specific impulse of the propellant alone. Thus a single number may be given which reflects improvements in case weight together with propellant performance. Early rockets were built such that I/W was only 20 per cent to 50 per cent of I_{sp}. Modern rockets may approach $I/W = 85$ per cent of I_{sp}. The theoretical upper limit for I/W is 100 per cent of I_{sp}.

Improvements in reliability and consistency of performance have been equally spectacular, owing to the application of modern techniques of quality control. It is now possible for ballistic properties of antiaircraft rockets to be so uniform that accuracy of fire is competitive with that of guns, and for the reliability of JATO units to be such that their use with both military and commercial aircraft is taken for granted (63).

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(*Continued on page 632*)

Twenty-Five Years of Ramjet Development

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Introduction

THE ramjet engine is the youngest of the family of jet propulsion devices that includes the squid, the rocket, the turbojet, and the pulsejet. Because the ramjet depends on its forward motion to achieve compression of the intake air, the engine itself employs no moving parts and is therefore capable of a simplicity and lightness of construction not possible in other air-breathing engines. This, plus the high thermal efficiency it can achieve, makes the ramjet a favored choice for propulsion of aircraft at supersonic speeds.

In the present article the history of ramjet development is briefly reviewed. This is followed by a summary of the design principles of ramjet engines. In the final section performance data for ramjets are compared with data for other jet engines.

Nomenclature

A	=	area
a	=	air mass flow rate
F	=	thrust
F_{bd}	=	drag force of combustor
f	=	fuel mass flow rate
M	=	Mach number
$\dot{m}$	=	mass flow rate
P	=	stream thrust
p	=	pressure
p_t	=	stagnation pressure
R	=	gas constant
S_a	=	air specific impulse
S_f	=	fuel specific impulse
T	=	absolute temperature
v	=	velocity
$\phi(M)$	=	Mach number function
γ	=	specific heat ratio
η_D	=	diffuser pressure recovery efficiency

Subscripts

0, 1–7	=	station reference numbers
a	=	air
c	=	value at Mach number unity
f	=	fuel
t	=	total or stagnation value

Superscripts

$'$	=	value behind normal shock

History

Apparently the first person to recognize the possibility of using ram pressure in a propulsive device was René Lorin of France, who published an article on the subject in *L'Aérophile* in May 1913. Lorin did not visualize flight at supersonic speeds and concluded that the efficiency of the engine would necessarily be very poor.

Benjamin Charles Carter, an Englishman, in a patent application (1)[2] filed in 1926, presented details of two ramjet-like devices for propelling shells, one with an annular duct and conical nose, the other with a cylindrical duct and normal intake. Carter showed considerable insight into the construction of a ramjet. He noted the problem of flameholding in an air stream of 300 ft/sec and proposed contrastream injection of fuel as a means of atomization and vaporization. He considered operation with combustor pressures of 2 to 6 times atmospheric (Mach 1 to 2) and ambient pressure as low as 5 psia (28,000 ft). Fig. 1 (from the patent application) shows Carter's two configurations. (The nozzle closure shown is detached after boost.) There is no evidence that any tests were made of Carter's invention.

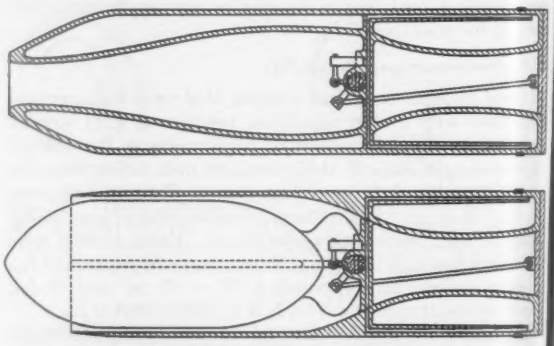

Fig. 1 Reproduction of figure from Carter's patent

The first description of a device which is clearly recognizable as a prototype of today's ramjets occurs in a German patent (2) applied for in 1928 by Albert Fono of Budapest. Fono describes its use specifically for supersonic flight and furnishes a design for a convergent-divergent inlet (Fig. 2). Fono's invention, like Carter's, apparently never progressed beyond the design stage.

During the 1930's interest developed in many quarters in high speed propulsion. Most of this took the form of rocket experimentation, but some pioneering was also done in ramjet propulsion. René Leduc of France in 1934 applied for a patent (3) on a design of a ramjet propelled airplane (Fig. 3). Leduc had begun ramjet research in 1933 and by 1935 had made tests of the thrust of a small unit at airspeeds as high as 679 mph. The tests convinced the Service Technique du Ministere de l'Air of the potentialities of this mode of propulsion, and they authorized the design and construction of a research airplane using ramjet power. A model of the airplane was exhibited at the Paris Salon d'Aviation in 1938 and work on the full scale airplane was begun at the Breguet plant near Paris in the same year. During 1939 tests of a double cone diffuser and other components were made at Mach numbers in the range 1.6 to 2.35. The German invasion of France essentially halted work until the Liberation but the project was then continued and a research airplane

[1] Physicist. Operating under Contract NOrd 7386 with the Bureau of Ordnance, Department of the Navy.

[2] Numbers in parentheses indicate References at end of paper.

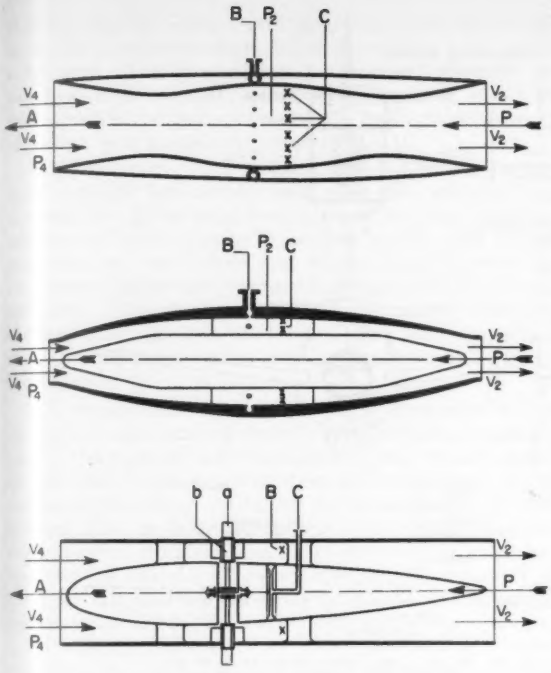

Fig. 2 Reproduction of figure from Fono's patent

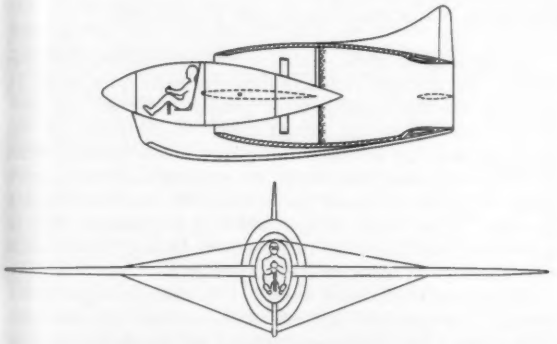

Fig. 3 Reproduction of figure from Leduc's patent

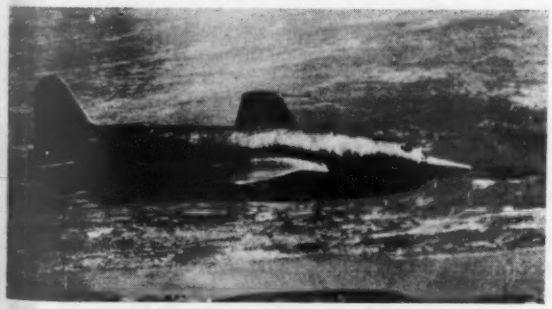

Fig. 4 Leduc 010 experimental aircraft in free flight
From "The Application of the Ramjet to Aircraft Propulsion," by M. Harned, *Marquardt Rep.* 502, 1952.

designated the Leduc-010, completed at the end of 1945. Actual powered flight tests (at subsonic speeds) were delayed until early in 1949 (Fig. 4), the intervening time being required for provision of a specially equipped plane to carry the 010 to flight speed and altitude and to tests of the aerodynamic characteristics of the plane. Improved versions of the airplane, which are expected to be able to cruise at more than 50,000 ft and to attain supersonic speeds, are reported to be under manufacture for the French Government.

Gohlke (4) has presented an interesting summary of patents issued for jet propulsion devices prior to 1940.

During World War II active work on ramjet propulsion was also begun in Germany, England, and the United States. In the latter two countries research and development have continued at an accelerated pace, and ramjet powered aircraft today play an important part in the national security programs. Unfortunately, security restrictions have severely limited the information published on most of this work and the material available for review can give a complete picture neither of the relative contributions of the various workers in the field nor of the status of development.

In Germany, Sänger and co-workers (5) began studies early in the war of the use of ramjets for fighters. After analysis indicated favorable application in high speed fighters and bombers, tests were made of experimental engines mounted on trucks and these were followed by tests of ramjets on an airplane. By 1943 sufficient data were available for the design of a ramjet propelled jet fighter which never was built (Fig. 5). Pabst and Lippisch of Focke-Wulf in Vienna were also engaged in subsonic ramjet research, now notable chiefly for the studies by Pabst of methods of fuel injection and flame stabilization.

A contribution of primary importance in the supersonic field was made by Oswatitsch (6) at Gottingen, Germany, who originated the spike type of diffuser which produces near-isentropic compression by deflecting the inlet air stream through a series of oblique weak shocks. Oswatitsch's group accumulated a mass of theoretical and experimental data on diffuser performance up to Mach 3. The work was intended for application to ramjet propulsion of a shell, but only preliminary trials were completed.

Work of the German groups also included the first studies of the possibilities of solid fuels for ramjets by Schwabl and Lippisch in Vienna and of the use of suspensions of metals (aluminum in fuel oil) by Sänger.

British work on ramjets, apparently stimulated by intelligence reports of German work, was begun early in the war. This was crystallized by the formation of a Guided Aerial Projectiles project in 1944 which undertook work on both rocket and ramjet propulsion. Although a rather complete theory of ramjet performance had been established by Reid and Herbert (7) by the beginning of 1946, experimental work appears to have lagged behind German, French, and American work.

In the United States the potentialities of ramjets for aircraft appear to have been first clearly pointed out by Stewart Way of Westinghouse, who wrote a report in July of 1941 (8) in which he analyzed the performance of ramjet powered subsonic airplanes. The analysis was accompanied by experiments with an electrically heated ramjet in which positive thrust was demonstrated (9). Studies of propeller-jet combinations were independently initiated at the National Advisory Committee for Aeronautics at about the same time by Williams (10). These were followed in September 1942 by a report by Becker and Baals (11) analyzing ramjet efficiency and describing tests of an idealized ramjet system carried out in Langley Laboratory wind tunnel in March 1941. The emphasis in these studies was on subsonic applications.

European and American workers by the beginning of the war had made much progress in the study of the aerodynamics of compressible flow (12). Understanding of the aero- and thermodynamics of high velocity flow in ducts with heat addition was advanced significantly by papers by Bailey (13) of General Electric published in 1944; by Chambre and Lin (14) of California Institute of Technology issued in 1946; by Hawthorne and Shapiro(15) of Massachusetts Institute of Technology; and Hicks, Montgomery, and Wasserman (16)

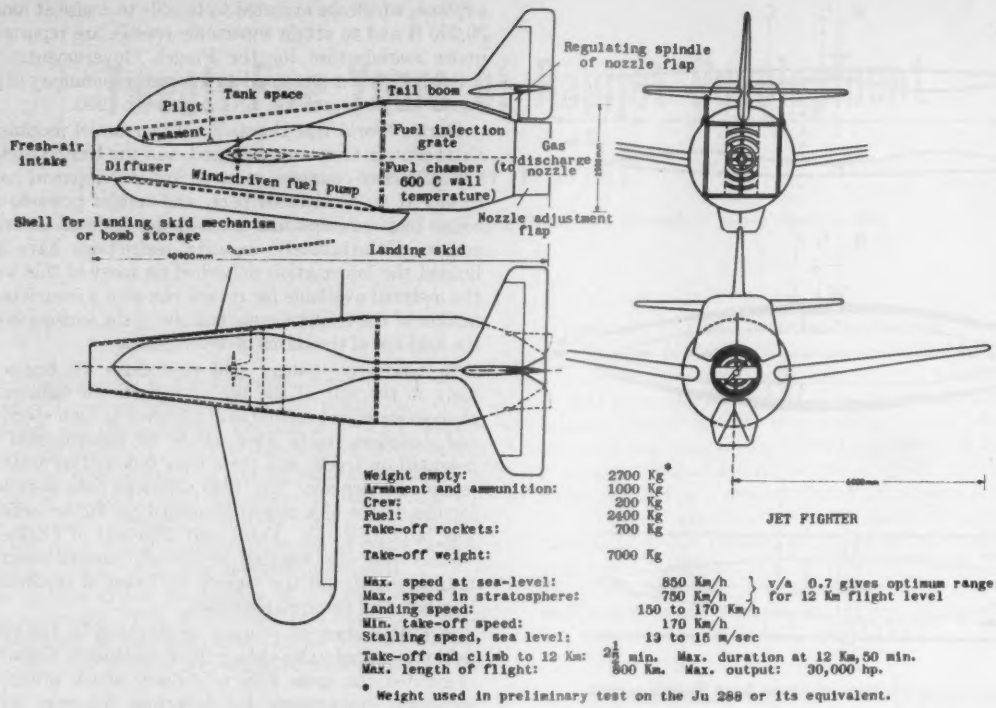
Regulating spindle of nozzle flap
Tank space
Tail boom
Pilot
Armament
Fuel injection grate
Fresh-air intake
Diffuser
Wind-driven fuel pump
Fuel chamber (to 600 C wall temperature)
Gas discharge nozzle
Shell for landing skid mechanism or bomb storage
Nozzle adjustment flap
Landing skid
Weight empty: 2700 Kg*
Armament and ammunition: 1000 Kg
Crew: 200 Kg
Fuel: 2400 Kg
Take-off rockets: 700 Kg
Take-off weight: 7000 Kg
JET FIGHTER
Max. speed at sea-level: 850 Km/h
Max. speed in stratosphere: 750 Km/h
v/a 0.7 gives optimum range for 12 Km flight level
Landing speed: 150 to 170 Km/h
Min. take-off speed: 170 Km/h
Stalling speed, sea level: 13 to 15 m/sec
Take-off and climb to 12 Km: 2½ min. Max. duration at 12 Km, 50 min.
Max. length of flight: 800 Km. Max. output: 30,000 hp.
* Weight used in preliminary test on the Ju 288 or its equivalent.

Fig. 5 Over-all arrangement drawing of a jet fighter with 60,000-hp jet unit

From "A Ram-Jet Engine for Fighters," by E. Sänger and I. Bredt, *NACA Tech. Memo.* 1106, October 1947.

of the National Advisory Committee for Aeronautics in 1947. These were followed in 1947 by a paper by Rudnick (17) of the Applied Physics Laboratory, who introduced the use of the "stream thrust" in analysis of ramjet performance and the terms "air specific impulse" and "fuel specific impulse." Rudnick introduced the system of calculations and analysis procedures that are in use today in a majority of ramjet programs. Alternative methods of analysis were devised in this period by Reid and Herbert (7), Rubert (18), Hill (19), Sanders (20), Samaras (21), and Collins and Gordon (22). All of these methods are basically equivalent since they are based on the same steady-state laws of thermodynamics and aerodynamics. Shapiro (23) has recently published a definitive treatise on the subject.

Experimental work on diffusers for high velocity engines was begun in 1942 at the NACA leading to important developments in the field of supersonic diffusers by Kantrowitz and Donaldson (24) in 1944 and 1945. They investigated the characteristics of reversed de Laval nozzles and demonstrated the difficulties in starting and maintaining stable operation of this type. Their work led to the development of the perforated diffuser, which is a possible type for improved supersonic operation (25).

The NACA was also engaged during the war in the study of flame stabilization in high velocity streams. Tests were made of spray and vaporizer chambers, including systems similar to those under development by Pabst in Germany which were shown to give reasonable efficiency with air speeds as high as 120 ft/sec. This work was part of a general program in jet engine combustion and was not aimed specifically at ramjet combustors.

After the disclosure in 1941 of the British gas turbine development, the Bureau of Aeronautics instituted combustion research programs at the National Bureau of Standards and Massachusetts Institute of Technology. Early in 1944 both these programs were extended to include ramjet combustion research, as performance studies undertaken within the Bureau of Standards indicated the advantages of this method of propulsion.

At the Bureau of Standards it was appreciated from the outset that new and radically different techniques would be required for the conditions of greatly increased approach stream velocity in the ramjet (26). In particular, it was assumed that fuel injection and mixing some distance ahead of the combustion zone would be required and that a pilot flame would be necessary to stabilize the main combustion process. Pilots with independent fuel supplies as well as pilots that used the main mixture were tested, but the main development was done with the latter type.

After some preliminary work in 1-in. pipes, a larger blower became available and the bulk of the testing was done on a 5-in. scale. The preliminary testing had employed city gas, propylene, and propane as fuels, but propane was used exclusively in the 5-in. tests. After considerable preliminary work, combustors were developed with an annular flameholder and later a combination of annular flameholder and central pilot. These chambers behaved well, giving stable combustion over an appreciable air-fuel range, including the stoichiometric value, and were relatively insensitive to fuel-injection pattern and distance between fuel injectors and flameholders. Unfortunately the blower could provide air velocities only up to 103 ft/sec at the test section so that the limiting velocity was not established.

It is now clear from the report of this work that the initial failures were due not to poor mixing, as was assumed, but to the small size of the flameholders in the early models. It should be emphasized that in employing only propane as fuel, the atomization and evaporation process had been effectively by-passed so that the results of this work were not immediately applicable to the problem of combustion of liquid hydrocarbons.

At the Massachusetts Institute of Technology the work was carried out in the Department of Chemical Engineering where a considerable experience on turbojet combustion chambers had been built up after 1942 (27). In the course of these studies improvements were achieved when fuel spilled into the secondary stream or when additional fuel was added after the piloting stage. This process of unloading the

primary zone was pursued until the primary zone had become atrophied to a simple hollow conical flameholder with a small entry area. This arrangement produced a very stable piloting zone of low heat output which served to ignite the fuel carried in the main air stream and, over limited ranges of operation, gave a satisfactory performance.

At a later stage in this program increased air supplies became available and development of an 8-in. chamber was undertaken. Initial tests were made with a multiplicity of unconnected small piloting cones, but trouble with partial extinction was encountered and it was found necessary to interconnect the pilots by gutters to maintain all the pilots in operation. This arrangement of piloting centers with connecting gutters has been the basis of many later combustion chambers and has proved to be entirely satisfactory for many applications.

It is worth recording that the M.I.T. investigators first realized the importance of correct fuel-air mixture preparation and, in the course of their experimental work, found it necessary to tailor the fuel-air distribution system very carefully to the flameholder array. A further fundamental difficulty was the fact that markedly different performance was observed when identical chambers were run on connected pipes and in free jets; this difficulty was to be a stumbling block in much of the later ramjet development. Finally, the importance of exit geometry and its effect on stability was first encountered in this experimental study.

In 1946 the development phases of the M.I.T. program culminated in the flight-testing of 20-in. subsonic ramjets on the wing tips of a P-51 aircraft, and sufficient data were secured to permit a realistic evaluation of subsonic ramjet propulsion. Although by this time the efforts in the United States had been focused on ramjet propulsion of supersonic missiles, the combustion problems were similar and all subsequent programs have embodied to a greater or lesser extent the findings of the pioneer work at M.I.T. and the Bureau of Standards.

In 1944 the Bureau of Aeronautics awarded a contract to the University of Southern California specifically calling for the development of a 20-in. subsonic ramjet. The project was headed by Roy Marquardt who left the University in 1945 to form a company to develop ramjet engines. The Marquardt Company produced its first flight-type engine in December of 1945. A 30-in. engine, mounted on the wing tips of an F-80 airplane, was used in 1946 for the first ramjet propulsion of a piloted airplane. The Marquardt Company has continued in the ramjet field and now is a leading manufacturer of both subsonic and supersonic engines.

In 1945 American work on ramjet development received a tremendous stimulus from the guided missile programs started at that time to counter the threat of Kamikaze attacks launched by airplanes flying beyond conventional antiaircraft range. The Bumblebee program, initiated by the Bureau of Ordnance and assigned to the Applied Physics Laboratory of The Johns Hopkins University in November 1944, was the first program that specifically called for the development of a ramjet engine to meet a tactical weapon requirement. Similar missile developments requiring ramjet power plants were assigned during 1945 and 1946 to the Boeing Airplane Company, Grumman Aircraft Corporation, Marquardt Aviation Corporation, and Massachusetts Institue of Technology.

Only partial accounts are available of the work of groups other than the Bumblebee project,[3] but the general developmental details of all the programs can be surmised from the brief summary that may be made of the Bumblebee effort. Because of the length and consistency of its support by the Bureau of Ordnance as well as the broad scope of the program, which has included research, development, and engineering, the Bumblebee program has played a leading role in the development of ramjet technology. Thus the history of this program to a certain extent typifies that of the entire program.

The primary tasks which faced the project at the beginning of 1945 were the setting up of a flight-test program and of laboratory facilities for completely realistic testing of flight models at full scale. Interim studies of 1-in.-diam engines were followed by the establishment of blow-down testing facilities sufficient to operate a 6-in.-diam engine, and by continuous-operation 6-in.-diam test facilities. Facilities for testing large engines at sea level began operating a little later. Flight-test vehicle fabrication was initiated and a fuel metering development program was begun.

Late in 1944 a 1-in. burner with a $^3/_8$-in. exit constrictor had been operated. The fuel used was acetylene, which was injected radially inward from the walls and spark-ignited. The fact that no flameholders were required was the first evidence of the spectacular properties of acetylene as a fuel.

In May 1945 new facilities allowed a simulation of true ramjet flight conditions for short periods (30 seconds to 1 minute) in a 6-in. parallel-sided chamber which was run with a variety of fuels. The stabilization problem was to some extent by-passed as oxyacetylene pilots were employed throughout the tests and attention was focused chiefly on fuel evaluation. One of the most interesting by-products of this work, however, was the attainment of flow rates and heat releases sufficient to produce sonic speed at the exit of a straight cylindrical combustion chamber. Such high air speeds at the entrance to a combustion chamber had not been attained before, although it was realized that they would be required of supersonic ramjet engines. In those early runs, smooth burning was possible over only a narrow range of air-fuel ratio (of the order 2/1), and the measurement of combustion efficiency was not easy.

Similar effort was concentrated elsewhere on establishing combustor designs suitable for flight test and yet capable of yielding performance equivalent or better than laboratory designs.

The Bumblebee flight program commenced early in 1945 when nonburning 6-in.-diam models were projected to study stability, drag, and launching techniques. Later in the year, hot rounds were fired and, in October 1945, a 6-in. unit burning heptane achieved the distinction of providing the first experimental demonstration of ramjet acceleration in supersonic flight. After these early successes, larger engines were designed and ground-tested. Less than two years after the start of the development, the first 18-in. test vehicle was successfully launched. This ramjet, which burned kerosene, not only functioned smoothly but produced an acceleration which increased the velocity to more than Mach 2.

Although these early successes were very spectacular and gave great impetus to the program, it must be noted that they were all low altitude flights and the test vehicles were equipped with only rudimentary fuel controls designed to maintain maximum thrust. The major part of the development problem thereafter was concerned with achieving satisfactory performance up to high altitudes together with control of the engine to maintain a desired Mach number or velocity program during flight.

Altitude flights demonstrated clearly the shortcomings of the sea-level designs and led to intensive development in

[3] It is worth noting that the advances in ramjet technology since 1940 have resulted largely from team research and widespread cooperation among governmental, university, and industrial organizations. Thus an attempt has been made in this review to identify organizations along with the individuals whose contributions have been noteworthy. The Bumblebee propulsion program has involved cooperation by the University of Virginia; The Johns Hopkins University; University of Wisconsin; Princeton University; University of Texas; Esso Research and Engineering Company; Convair, A Division of General Dynamics Corporation; Bendix Aviation Corporation; Experiment, Inc., and McDonnell Aircraft Corporation.

low-pressure ground-test facilities, first at the 6-in. scale, later at full scale. In the meantime, accurate fuel controls to operate over a wide pressure range had been developed.

Effort was required to integrate this successfully controlled engine with the beam-rider missile, and it was not until some time later that a beam-riding ramjet-propelled missile was first demonstrated. (See front cover, this issue JET PROPULSION, showing launching of a Bumblebee ramjet test vehicle with its booster rocket.)

Ramjet Design

As mentioned earlier, the ramjet engine in its basic elements is the simplest air-breathing power plant. There are three principal components of the ramjet itself (Fig. 6): (a) the *diffuser*, through which air is admitted to the engine and in which the velocity is reduced and ram pressure developed; (b) the *fuel injection system*, with which fuel is introduced, vaporized and distributed; and (c) the *combustor*, which includes a flameholder, the combustion zone where heat is released, and a nozzle through which the burned gases are ejected rearward at high velocity. The engine requires a *fuel control system* to adjust the fuel rate to the air rate as this varies with aircraft altitude and flight speed and to control the flight speed of the aircraft to the desired values. In addition an auxiliary power plant, usually a rocket, must be provided to accelerate the aircraft to a speed at which the ramjet can provide useful thrust.

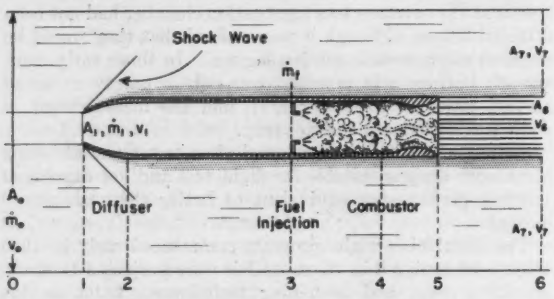

Fig. 6 Ramjet airflow diagram

In the following sections we shall indicate the factors important in over-all ramjet design and then discuss briefly the developmental status of the four major components.

Engine Performance

In supersonic aircraft the aerodynamic drag and the off-design characteristics of the engine as well as the rated thrust have such a pronounced effect on the aircraft construction and performance that it is necessary to integrate fully the design of airframe and power plant if an efficient configuration is to be achieved. This necessitates a process involving many iterative stages of composite design and performance analysis before a final optimum is reached. However, this fact being noted, we shall assume in the following paragraphs that the engine designer begins his work with the following parameters specified by composite design considerations.

A. Cruise Mach number with allowable tolerances and requirements for acceleration to cruise speed after launch.

B. Required thrust as function of altitude and maneuver. (Includes allowable reduction in thrust with angle of attack.)

C. Fuel type and maximum allowable combustion chamber temperature.

The operation of a ramjet engine is depicted schematically in Fig. 6. To simplify the discussion we assume that the ramjet is stationary and that air approaches the engine at velocity v_0. We shall consider an approach air stream of sufficiently large cross section so that pressure is atmospheric along the boundaries. In the case shown, the engine operates with a normal shock at the diffuser inlet and the stream tube of the inlet air is a normal cylinder. The air flowing around the outside of the engine suffers momentum losses due to skin friction so that the mean velocity v_7 of the external air at station 6 is less than v_0.

The inlet air, after fuel injection and combustion, is exhausted from the nozzle at a high velocity, v_6, which changes to v_6 when pressure equilibrium with the atmosphere is established.

From Fig. 6 it is apparent that the thrust of the engine is equal to the difference between the momenta of the gases passing the control surfaces at stations 6 and 0. Thus

$$F = (\dot{m}_0 - \dot{m}_1)v_7 + (\dot{m}_1 + \dot{m}_f)v_6 - \dot{m}_0 v_0 \quad \ldots\ldots [1]$$

or

$$F = \dot{m}_1(v_6 - v_0) + \dot{m}_f v_6 - (\dot{m}_0 - \dot{m}_1)(v_0 - v_7) \quad \ldots\ldots [2]$$

The last term in Equation [2] represents the momentum loss due to external drag and is usually included in the airframe drag calculations. If the inlet and exhaust pressures are ambient so that

$$A_0 = A_1 \quad \ldots\ldots [3]$$

and

$$A_5 = A_6 \quad \ldots\ldots [4]$$

the net thrust of the power plant is

$$F = \dot{m}_1(v_6 - v_0) + \dot{m}_f v_6 \quad \ldots\ldots [5]$$

In the general case, Equations [3] and [4] do not hold, so that the thrust includes a term involving the difference in pressure between the inlet and exit.

$$F = \dot{m}_1(v_6 - v_1) + \dot{m}_f v_6 + p_6 A_6 - p_1 A_1 \quad \ldots\ldots [6][4]$$

The similarity of Equation [6] to the expression for rocket thrust will be apparent to readers of this Journal. However, ramjet thrust calculations are considerably more complicated than those for rockets because the exhaust geometry and gas velocity depend on an interaction and balance between the pressure developed in the diffuser and that in the combustor.

In making such calculations it is found convenient to convert the familiar conservation equations of mass, momentum, and energy to forms involving Mach number (13) and to combine these into expressions employing the stream thrust as a parameter (17).

The stream thrust P at a particular cross section in a duct is defined by the equation

$$P = pA + \dot{m}v = pA(1 + \gamma M^2) = \frac{\dot{m}}{M}\sqrt{\frac{RT}{\gamma}}\,(1 + \gamma M^2) \quad \ldots\ldots [7]$$

The stream thrust is a particularly useful quantity in ramjet calculations because the difference in stream thrust between two stations is equal to the thrust exerted in an axial direction on the duct walls between the two planes.[5] The stream thrust P may also be expressed as a function of mass flow, stagnation temperature, and Mach number. Thus

$$P = \dot{m}\sqrt{\frac{2(\gamma+1)}{\gamma}RT_t}\;\frac{1 + \gamma M^2}{\sqrt{2(\gamma + 1)M^2\,[1 + {}^1/_2(\gamma - 1)M^2]}} \quad \ldots [8]$$

or

$$P = \dot{m}\sqrt{\frac{2(\gamma + 1)}{\gamma}RT_t}\;\phi(M) = P_c\,\phi(M) \quad \ldots\ldots [9]$$

The Mach number function, $\phi(M)$, reduces to the value unity when the Mach number is unity, i.e., at a throat or

[4] Gage pressures are used in this equation, otherwise an additional term $p_0(A_1 - A_6)$ is needed.

[5] If the flow is not unidimensional and axially symmetric, a more general definition of the stream thrust is required (17).

choking section of the duct. Thus P_e is a direct measure of the exit stream thrust of a ramjet equipped with a non-expanding exit nozzle. This stream thrust for unit mass flow and nozzle area depends only on the mean stagnation temperature and heat capacity ratio. Thus it is a useful measure of the combustor performance, analogous to the characteristic gas velocity familiar to rocket designers.

It is convenient to define a *fuel specific impulse*, S_f, and an *air specific impulse*, S_a, by the relations

$$fS_f = aS_a = P_e \quad \ldots\ldots [10]$$

These quantities are easily measured on the test stand with a connected pipe installation by arranging the inlet air flow at right angles to the duct axis so that the inlet stream thrust is zero.

With the quantities defined above, the equation of state, and the Mach number functions[6] in Table 1 (at end of paper), ramjet design is straightforward but involves successive approximations. A procedure is summarized below to illustrate the method.[7]

Using the engine configuration shown in Fig. 6 and assuming the design condition of normal shock at station 1, we may design an engine as follows:

With sonic conditions existing at the exit nozzle throat, it is most convenient to express the internal losses in terms of total pressure ratios so that

$$p_{t5} = p_{t0} \times \frac{p_{t1}}{p_{t0}} \times \frac{p_{t2}}{p_{t1}} \times \frac{p_{t4}}{p_{t2}} \times \frac{p_{t5}}{p_{t4}} \quad \ldots\ldots [11]$$

p_{t0} is the free stream stagnation pressure and is determined by the design flight condition. p_{t1}/p_{t0} is the total pressure ratio across a normal shock and is a function of flight Mach number. p_{t2}/p_{t1} is the subsonic diffuser efficiency η_d. p_{t4}/p_{t2} includes all losses across the combustor due to fuel injection, drag and heat addition and may be estimated from detail calculations or from past experience with similar systems. p_{t5}/p_{t4} is the total pressure ratio across the exit nozzle.

Assuming that the nozzle exit is sized to provide an expansion to ambient pressure, the exit Mach number M_5 may be determined from the ratio p_5/p_{t5} and the exit stream thrust may be expressed

$$P_5 = p_0 A_5 (1 + \gamma_5 M_5^2) \quad \ldots\ldots [12]$$

The exit stream thrust may also be expressed

$$P_5 = aS_a\phi(M_5) \quad \ldots\ldots [13]$$

S_a is a function of the inlet total temperature, the fuel, the fuel-to-air ratio, and the combustion efficiency, which are parts of the design condition assumption. The inlet stream thrust for shock on the rim may be expressed

$$P_1 = p_0 A_1 (1 + \gamma_0 M_0^2) \quad \ldots\ldots [14]$$

Using the mass flow function at the inlet

$$\frac{a\sqrt{T_{t0}}}{p_0 A_1} = f(M_0) \quad \ldots\ldots [15]$$

the inlet stream thrust may be expressed

$$P_1 = \frac{a\sqrt{T_{t0}}}{f(M_0)} (1 + \gamma_0 M_0^2) \quad \ldots\ldots [16]$$

and the net propulsive thrust

$$P_5 - P_1 = aS_a\phi(M_5) - \frac{a\sqrt{T_{t0}}}{f(M_0)} (1 + \gamma_0 M_0^2) \quad \ldots\ldots [17]$$

[6] Tables of the Mach functions have been compiled to facilitate ramjet calculations (28).

[7] A concise but somewhat more detailed summary has been presented in this Journal by Marsh and Sears (29).

The thrust is then expressed in terms of the air flow. The required inlet and exit areas may be determined from relations [12] and [14].

The combustion chamber area A_2 to A_4 is determined by the allowable pressure losses across the combustor which are excessive at high Mach numbers. A normal value for M_2 is approximately 0.15.

Diffuser Design

Ideally, a diffuser configuration should be chosen that will give isentropic compression of the supersonic approach stream with continuous reduction of the air speed to the final value appropriate to the through duct. Diffusers of the isentropic spike type devised by Oswatitsch and of the modified de Laval type designed by Evvard and Blakey can give a close approach to such compression. However, the off-design performance of such diffusers deteriorates rapidly with angle of attack and change in Mach number and the external drag may be high. Thus for practical operation a normal-shock type is found to be optimum for speeds up to about Mach 2, and a conical spike, single-oblique shock is preferred up to about Mach 2.5. At higher speed, optimum performance may be found with two or more oblique shocks (Fig. 7).

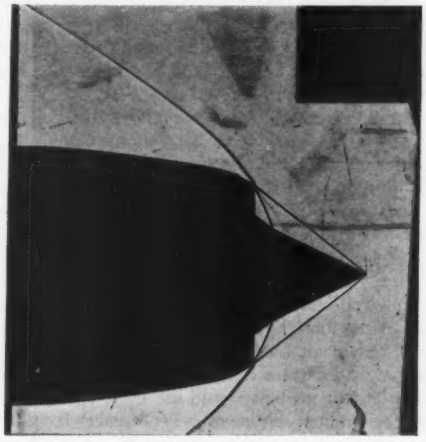

Fig. 7 Double cone diffuser operating at design Mach number

The steady state performance of supersonic diffusers is well understood and full scale diffusers may be designed for accurately predictable pressure recovery and air flow reception. Time dependent phenomena are less well understood, particularly "buzz," an oscillatory condition found with spike diffusers operating at an off-design condition in which part of the air compressed supersonically spills outside of the inlet. "Buzz" involves a rapid forward and back movement of the shock pattern at the diffuser inlet accompanied at high Mach numbers by pressure oscillations that may be of destructive intensity. Problems also exist in the design and testing of unsymmetrical configurations such as scoops or off-axis inlets, and with diffusers close-coupled to the combustors so that asymmetries in the subsonic flow at the inlet can affect the combustor operation.

Fuel Injection and Distribution

The high velocity flow into the combustion zone of practical ramjets with the accompanying high turbulence level and the presence of wakes, eddies, and recirculation zones generated by upstream spars, air intakes, etc., creates problems of extreme complexity in the achievement of a straightforward design method for fuel injection, vaporization, and controlled distribution. Practical solutions have been found

to date largely in cut-and-try procedures involving use of an arbitrary number of fuel injection points and variation of the geometrical arrangement and nozzle vaporization characteristics empirically until a satisfactory fuel distribution pattern has been found. Impressive progress has been made, however, in the establishment of engineering design formulas for predicting the rate of fuel spreading from point, disk, and ring sources in a turbulent stream of known intensity (30, 31) and in prediction of the degree of vaporization that will occur in a known time for a particular nozzle type.

Combustor Design

In the development of the first ramjet combustors a major problem was encountered in maintenance of a stable flame in the high velocity flow through the combustor. A solution to the problem was found in the introduction of bluff bodies (baffle flameholders) in the duct, behind which recirculation zones were formed and the flow was sufficiently slow to permit a stable flame to be established. The same result could be achieved by passing the inlet material to the combustor through holes or slots in a perforated plate or cone mounted in the duct. Combustors with the first type of flameholder have come to be called baffle-type combustors, while the latter type are known as "can" combustors.

It was recognized early by the groups at M.I.T. and the Bureau of Standards that a relationship existed between the flameholder dimensions and the flame blow-off velocity, also that the blow-off velocity depended on the fuel-air ratio of the stream impinging on the baffle. Systematic studies of the phenomenon by Scurlock (32) at M.I.T., Longwell (30, 33) at Esso, and DeZubay (34) at Westinghouse showed that blow-off limit at a given fuel-air ratio was approximately proportional to the pressure and effective diameter of the baffle, and inversely proportional to the velocity of flow past the baffle.

The variation of blow-off limit with fuel-air ratio found by DeZubay is shown in Fig. 8. The experimental points indicate the degree of precision of the correlation. Zelinski Rosen, and Walker (35) have shown recently that the DeZubay-Longwell relationship may be improved by a different grouping of parameters and that a similar relationship may be applied to can combustors.

With fuel distribution and stability limits defined in terms of the combustor geometry and air flow, one further major design criterion, heat release rate, is necessary to complete the basic requirements for combustor design. For a given cross-sectional area the latter quantity determines the length of combustor required to achieve a desired combustion efficiency.

It is evident that the heat release rate for a baffle combustor

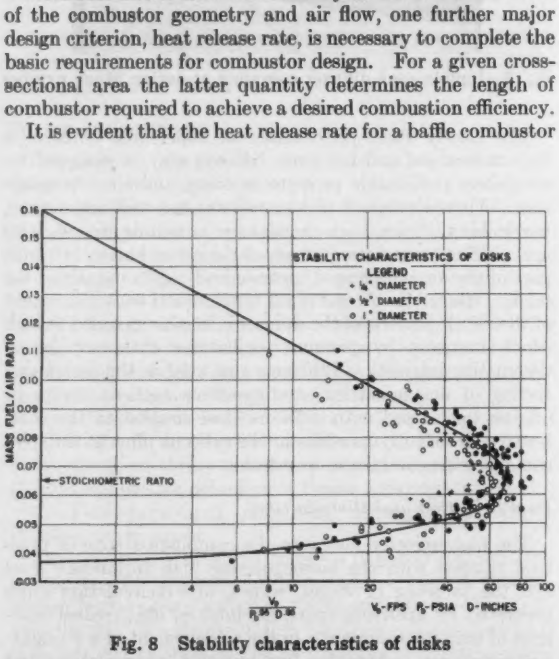

Fig. 8 Stability characteristics of disks

From "Characteristics of Disk-Controlled Flame," by E. A. DeZubay, *Aero Digest*, vol. 61, July 1950, p. 54.

will depend on the rate (or angle) at which the flame spreads into the unburned material from the stabilizing baffles. A combustor length will be required that is somewhat greater than the distance needed for the flame from one baffle to spread to the wall or to come in contact with the flame spreading from another baffle. In a can combustor the unburned material issues into the combustion zone in the form of jets which are gradually consumed. The "jet length" in this case determines the required combustor length.

Several papers have been published on rates of flame spreading from baffles (36), and Zelinski, Matthews, and Bagnall (37) have recently reported the results of a study of the burning rates of confined turbulent jets.

In effect, both baffles and cans may be thought of as devices to introduce sources of ignition from the burned material into the entering combustible mixture. The rate of heat release depends then on the mixing rate and the rate of combustion once an ignition source has been provided. One is led thus to consider types of mixing devices that might lead to maximum heat release rates. This line of reasoning led Avery and Hart to consider what performance might be expected in a combustor in which perfect instantaneous mixing could be achieved (38). They found that definite blow-off limits would exist for such a combustor, defined by the chemical kinetic behavior of the fuel, and that a maximum heat release rate proportional to the square of the pressure for a second-order reaction could be computed. Experimental work by Longwell and Weiss (39) at Esso, who developed a spherical reactor in which very high mixing rates could be achieved, and by the Applied Physics Laboratory group have shown that the theoretical maximum heat release rate for hydrocarbon fuels at normal inlet temperatures is approximately 400 million Btu/atm$^{1.8}$ ft^3 hr. The largest experimental value that has been reported for a ramjet combustor is about 20 million Btu/atm^2 ft^3 hr (40). The comparison shows clearly that great gains in heat release rate are possible if more efficient mixing devices than simple cans or baffles can be developed.

Fuel Metering and Control

No published material has been found on fuel metering and control systems for ramjets. However, the requirements of the system are apparent and may be readily outlined. Operation of the ramjet from sea level to altitudes in excess of 60,000 ft will lead to a variation in air flow rate of a factor of ten to fifteenfold. In addition there will be requirement for a two to fourfold variation in fuel flow at a given Mach number and altitude between a lean value for low-drag cruise and a rich value for acceleration and maneuver conditions. Thus the meter must be designed to control fuel flow within, say, $\pm 5\%$ over a fiftyfold variation in total flow. The requirement is a stringent one that leads to a need for precise construction and close tolerances. Intelligence for the speed control may be provided in a number of different ways, the general features of which are readily apparent. For example, fuel rate may be set proportional to ram pressure which is approximately proportional to the air rate near the design Mach number. Mach number may be determined by the ratio of ram pressure to static pressure and a correction applied to the measured ram pressure to adjust fuel flow to the correct value to cause the vehicle to achieve the desired Mach number. If velocity control is desired, a measurement of the total temperature may be used as a basis for conversion of Mach number to velocity. Mechanical, hydraulic, or electronic servo systems may be employed to achieve the desired accuracy and quickness of response of the control system. The system must, of course, be designed to be insensitive to inertial loads either from the rocket boost or from flight maneuvers. Attention is also necessary to possible effects of aircraft angle of attack on the sensing elements and control requirements, and on the possibility of unstable operation resulting from interaction between the combustor or the diffuser and the metering system.

Ramjet Applications and Potentialities

The selection of an aircraft power plant involves consideration of many aspects of its performance and use, of which the following may be selected as of primary importance.

Performance:
- Thrust per unit frontal area.
- Thrust per pound of engine weight.
- Fuel consumption rate per pound thrust.
- Speed and altitude boundaries for efficient operation.

Cost.
Flexibility in installation.
Reliability.[8]

Thrust per Unit Frontal Area

Since the lift-to-drag ratio of supersonic aircraft is a tenth to a quarter that achievable in subsonic types, the thrust required in high speed planes to carry a given payload becomes relatively large. Engine drag thus becomes an important part of the over-all drag, and thrust per unit frontal area is a characteristic of primary importance in engine selection. In Fig. 9 the thrust per unit frontal area of the ramjet as it depends on Mach number is presented in comparison with the rocket, turbojet, and turbojet with afterburner. Above Mach 2 the ramjet is seen to be superior to the turbojets in thrust per unit area.

Thrust per Unit Weight

The same reasons that make thrust per unit area of importance make the thrust delivered per pound of engine weight of relatively great significance for supersonic propulsion. Comparative data as estimated by Harned (41) are presented in Fig. 10.[9] In this respect the ramjet is seen to be markedly superior to the turbojets.

Fuel Specific Impulse

Fuel specific impulse determines the aircraft range and is of primary importance for long range aircraft. For short range designs it may be of little significance. The fuel specific impulse of the ramjet, shown in Fig. 11, is relatively poor until speeds above Mach 2 are reached, but above this point it is superior to that of all the other power plants. It is interesting to note that the ramjet fuel consumption in lb fuel per mile per lb thrust during cruise at Mach 2 or above would be better than that of a piston engine propelling a subsonic plane. However, the piston engine would have some advantage in miles per gal per lb of payload because of the higher lift-to-drag ratio of subsonic planes (20-1 vs. 3 to 5 to 1).

Speed and Altitude Limits

The speed and altitude limits of conventional ramjets are shown in Fig. 12. The upper boundary on the speed is imposed by the air stagnation temperature which at Mach 4 will be between 1500 and 2000 F. Higher heat transfer rates in denser air cause the temperature limit to be reached at a somewhat lower speed at sea level. At the "thermal boundary," about Mach 4, materials problems for aircraft and engine construction become severe (unless cooling were provided, the aircraft would have to operate at a red heat). Furthermore, the thermal efficiency of the engine decreases because dissociation of the products of combustion

[8] A fifth item of major importance in power plant selection is a predisposition on the part of the airframe designer or sponsor for a particular engine type, which derives from a background of experience with that type of power plant. Discussion of this point is considered outside the scope of the present article.

[9] Slightly different assumptions have been made in the estimates of engine performance presented in Fig. 10 and those in Figs. 9 and 11; hence the data are not strictly comparable.

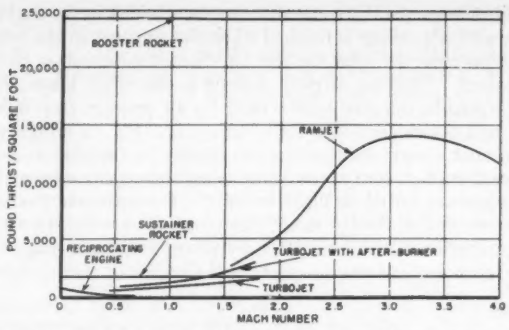

Fig. 9 Typical thrust available per sq ft of frontal area for engines of various types (sea level operation). Supplied by J. H. Walker, APL

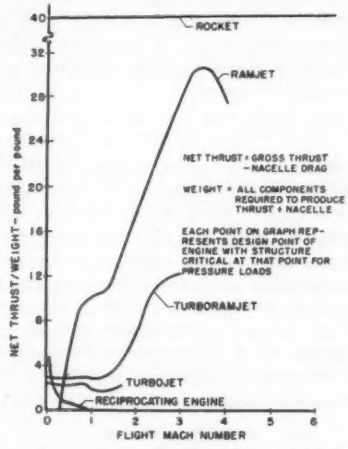
ROCKET
RAMJET
NET THRUST = GROSS THRUST - NACELLE DRAG
WEIGHT = ALL COMPONENTS REQUIRED TO PRODUCE THRUST + NACELLE
EACH POINT ON GRAPH REPRESENTS DESIGN POINT OF ENGINE WITH STRUCTURE CRITICAL AT THAT POINT FOR PRESSURE LOADS
TURBORAMJET
TURBOJET
RECIPROCATING ENGINE
NET THRUST/WEIGHT - pound per pound
FLIGHT MACH NUMBER

Fig. 10 Comparison of ratios of thrust to weight for engines of various types

From "The Application of the Ramjet to Aircraft Propulsion," by M. Harned, *Marquardt Rep.* 502, 1952.

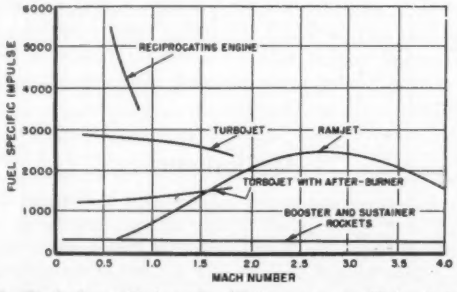

Fig. 11 Typical specific impulse (lb thrust × sec/lb fuel) derived from various types of engines. Supplied by J. H. Walker, APL

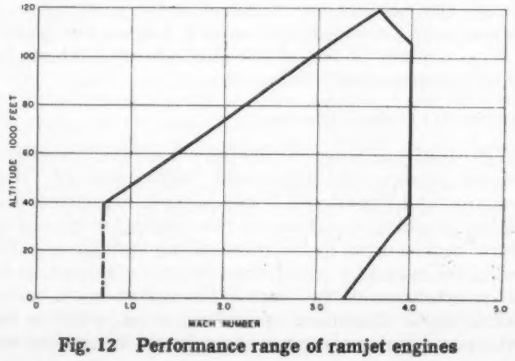

Fig. 12 Performance range of ramjet engines

limits the temperature rise that can be attained in the engine. The altitude ceiling is reached when the pressure in the combustion chamber falls too low for efficient combustion to be obtained. In most aircraft designs a somewhat lower ceiling would be imposed by the need for air pressure to provide lift and maneuverability for the aircraft. Fig. 12 brings out the most serious drawback of the ramjet, its inability to produce thrust at zero speed and the accompanying strong dependence of thrust on flight velocity. Evaluation of the usefulness of the ramjet must, therefore, always consider the combination of ramjet and boost power plant and judge the fuel economy and engine weight of the combined power plant.

Cost

Production costs of ramjet engines may be expected to be low in comparison to turbojet or piston types because of their simplicity and their ability to use ordinary construction materials. In addition, the large advantage of ramjet engines in thrust per lb of engine weight leads to material savings in power plant costs. Engine cost in dollars/horsepower for Mach 2 flight may be estimated at $0.50 vs. $8 to $10 for turbojet engines.

Flexibility

As was mentioned earlier, the efficient design of supersonic aircraft requires a happy marriage of power plant and airframe. The design method which involves tacking a developed engine to a developed airframe has many features of the shotgun wedding and the same poor chances of success. A policy of design of airframe and power plant as a unit places a premium on engine flexibility in redesign to accommodate desired changes in dimensions or performance. Becase of the simplicity of the ramjet, small changes in scale or performance may be readily accomplished without necessitating extensive redesign, retooling, or new test programs.

Reliability

It is axiomatic that no power plant can be accepted for service or commercial use which does not give reliable performance. Thus the need for reliability in complex power plants or in those requiring close tolerances tends to be reflected in a need for extensive quality control and hence greater cost and decreased production rates. The simplicity of the ramjet engine, with its complete absence of moving parts exposed to hot gases, makes it extremely attractive in this regard.

Applications

The data presented above indicate that the ramjet will be favored over other power plants in applications in which appreciable range is required at speeds greater than Mach 2, where engine weight or drag is a significant fraction of the weight or drag of the aircraft; where engine cost is of major importance; and where the need for auxiliary boost is not a primary disadvantage.

Space does not permit a discussion of the potentialities of ramjets for all present military aircraft, but is is worth while to discuss briefly a few of the applications in which the ramjet is a pre-eminent choice.

Antiaircraft Guided Missiles

High speed and range capabilities are required in missiles designed to cope with high speed bomber attacks. High thrust per unit frontal area is important in minimizing drag and has an added importance in this application in reducing volume requirements in the missile-firing installation. The need of the ramjet for rocket boost is not a disadvantage for antiaircraft applications because the rocket boost makes possible quick attainment of cruising speed, which is important in reducing the range of minimum engagement and the time to target. Specific fuel consumption is not of primary importance for this use, but values as high as those typical of rockets cannot be tolerated for ranges greater than about 30 miles. The simplicity and low cost of the ramjet as well as its outstanding performance at high speeds make it a pre-eminent choice for antiaircraft missiles.

Target Drones

In this application, low cost of the power plant is of primary importance. The Marquardt Company has demonstrated that a subsonic ramjet may be manufactured for drone use at a cost of $0.50 per horsepower compared with an extimated $5 per horsepower for piston engines.

Long Range Bombardment Aircraft

The greater efficiency of the ramjet at high speeds gives it an advantage for applications requiring long range with cruise speeds above Mach 2. Whether ramjet propulsion is the optimum choice for long range attacks depends on an evaluation of the relative merits of piloted vs. unpiloted aircraft and of high speed cruise vs. cruise at subsonic speed plus supersonic approach to the target. Turbojets would be favored for the first of each of the alternatives mentioned. However, it is clear that the development of defense possibilities against bombardment will call for higher and higher attack speeds. With progress in automatic control it seems clear that piloted subsonic airplanes will become obsolete for bombardment applications.

Nuclear Powered Ramjet

Ramjet propulsion is an ideal field for the application of nuclear reactors. Since air is the working fluid and no moving parts are necessary, all that is required is a nuclear heat source with a heat exchanger sufficiently low in drag to permit reasonable efficiency to be attained. The nuclear powered ramjet plane would appear likely to become the favored transport plane for transcontinental and transoceanic applications in the future.

Conclusion

Ramjet engines have been under active development only since the war, but in this short period they have assumed a leading position in the propulsion of supersonic aircraft. We may expect this position to be strengthened in the future to the point that ramjet power plants will be in dominant use in most fields of aviation.

Acknowledgments[10]

I wish to express appreciation to Drs. W. H. Goss and H. M. Nicholson for permission to use portions of their survey paper on ramjet technology for the section on the history of American work. I wish also to thank Mr. W. B. Shippen for helpful discussions of the paper and assistance in preparation of the section on ramjet performance; Mr. E. J. Hardgrave for comments on the manuscript; Mr. L. Canter and the A.P.L. library for assistance in compiling the bibliography; Dr. F. Palmer for many helpful suggestions on the presentation of the material; and Miss Ann C. Hall for typing and editing assistance. Finally I wish to acknowledge the kind permission granted by the Marquardt Aircraft Corporation for the use of Figs. 4 and 10, the Aeronautical Digest Publishing Corporation for Fig. 8, and Mr. J. H. Walker of the Applied Physics Laboratory for Figs. 9 and 11.

[10] The author would welcome receipt of additional historical material or references from persons or organizations who have made significant contributions to ramjet development, but who because of inadequate time for clearance or assembly of material were unable to forward it for inclusion in this review. A summary of the material will be presented in a future issue of this Journal.

Table 1 Mach number functions

Pressure ratio vs. Mach number.

$$\frac{p}{p_t} = \left[1 + \frac{\gamma - 1}{\gamma} M^2\right]^{-\frac{\gamma}{\gamma - 1}}$$

Area ratio vs. Mach number.

$$\frac{A}{A_e} = \frac{1}{M}\left[\frac{2 + (\gamma - 1)M^2}{\gamma + 1}\right]^{\frac{\gamma + 1}{2(\gamma - 1)}}$$

Temperature ratio vs. Mach number.

$$\frac{T}{T_t} = \left[1 + \frac{\gamma - 1}{2} M^2\right]^{-}$$

Mach number relation across a normal shock.

$$M_2^2 = \frac{2 + (\gamma - 1)M_1^2}{2\gamma M_1^2 - \gamma + 1}$$

Stagnation pressure ratio across a normal shock vs. Mach number.

$$\frac{p_t'}{p_t} = \left[\frac{\frac{\gamma + 1}{2} M^2}{1 + \frac{\gamma - 1}{2} M^2}\right]^{\frac{\gamma}{\gamma - 1}} \left[\frac{2\gamma}{\gamma + 1} M^2 - \frac{\gamma - 1}{\gamma + 1}\right]^{-\frac{1}{\gamma - 1}}$$

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History, Problems, and Status of Guided Missiles

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Introduction

BECAUSE of the rapid progress in guided missiles in the past 25 years, and particularly since World War II, this article can do no more than present a brief résumé of the major activities in a field which may have a profound and significant impact on the future of the human race. Since World War II, the primary emphasis has been toward developing missiles for immediate military objectives. But with the announcement of the proposed satellite program and the approach of the International Geophysical Year, interest in essentially nonmilitary applications of guided missiles for high-altitude research is increasing. The long-range effect of this will be all to the good. In time, the guided missile may become, if not less a weapon of destruction, more a scientific tool.

Against this background of increasing general interest is a solid body of experience and knowledge which has been growing steadily since the war. With the redirection of the policy of the Defense Department toward increasing research and development (it is now spending as much in this field as in the field of piloted aircraft), this growth should be measurably accelerated. The potentials of this reservoir can scarcely be guessed at. One thing is certain—it will make valuable contributions to the scientific community and to industry at large. As in the past, equipment developed primarily for the military will be absorbed by civilian industry. Portions of the guidance systems for missiles are being applied to aircraft; and the power plants of weapons will be converted to peaceful usages in the continuing effort to remove the barrier of distance from the affairs of men.

History

The technology of guided missiles, in the twentieth century at least, involves several complex fields of scientific endeavor; consequently, it is impossible to attribute the first attempts—the invention of the guided missile—to any one group of experimenters or to any single inventor. The guided missile is a synthesis of concepts that are very old and durable and very new and unproved. In the classic sense, the first guided missile used the power of the human muscle and the guidance of the human eye. The first stabilized projectile might well have been a feathered arrow, invented in a time beyond memory and employed against an enemy long since forgotten. Today, although the power plants are more powerful and the guidance systems more efficient and responsive, the fins remain. They stabilize some of our smallest air-to-air armament rockets and some of our largest, long-range ballistic missiles and function together with design concepts far removed from a caveman culture to form an integral part of contemporary guided missile systems.

For the purpose of this discussion, the first guided missile—in the twentieth-century sense—can be credited to Professor A. M. Low, who, with his team of British experts, began experiments in 1914 on small, pilotless aircraft powered by internal combustion engines. A simple radio command time-switching scheme was used for guidance. Several flights were accomplished in 1916 and 1917, although the lack of an autopilot prevented successful performance. In this country, Professor Low's contemporaries, C. F. "Boss" Kettering and Elmer Sperry experimented with a flying bomb which was guided by an automatic pilot, had a range of 50 miles, and a top speed of 90 mph. It was gyroscopically stabilized, maintained its altitude with a barometer, and flew a predetermined distance by means of an "air-log." Other versions were flown at the U. S. Naval Proving Ground at Dahlgren, Va., around 1920. In France and Germany experiments were conducted with gyro stabilized pilotless aircraft at the end of World War I. In the 1920's and 1930's there was little interest in automatic flying devices, and the development effort was sporadic and on a very small scale. It was only as recently as December 1937 that the first flight of a radio controlled airplane using automatic landing techniques was accomplished—a few months over ten years after Lindbergh flew solo across the Atlantic Ocean, and 28 years after Marconi received the Nobel Prize in physics. A few years later, during World War II, the guided missile as we know it today emerged. In Germany the V-1 pulsejet pilotless monoplane and the V-2 rocket-powered gyro-controlled missile were developed, produced, and employed against actual military targets. Both carried approximately 2000 lb of explosive warhead, and their impact on the world was far greater than their radius of destruction. By the end of the war, a number of nations were working on similar guided missiles. And ten years after the experiment in 1937, automatic pilots daily guided commercial aircraft from New York to Shannon, Ireland.

The V-1, first wartime guided missile, obtained its directional control by compass and gyroscope, flew at an elevation of 3000 ft and at a speed of approximately 400 mph. Thousands were produced and launched against the Allies. But being incapable of evasive action, the V-1 was very vulnerable to countermeasures, and only a small percentage of them ever reached their targets.

The V-2 was a supersonic guided missile of less than 30,000 lb gross weight, capable of a maximum range of about 200 miles. Countermeasures against it were extremely difficult. At the end of the war, this particular guided missile posed developmental problems—such as structural failure upon re-entry into the atmosphere—which have not been fully solved many years later.

The V-1 cost approximately $13,000 apiece, and the V-2 cost in the neighborhood of $50,000 to $60,000 each. Some of the larger guided missiles in production today, of course, cost much more per unit, and intercontinental missiles are extremely expensive. But the cost to defend against long-range missiles—to establish and maintain radar warning nets to staff and service defensive sites around military targets and population centers, and to develop workable methods and avenues for mass evacuation of civilians—is truly astronomic. Because of its effectiveness per unit and its high degree of invulnerability, the guided missile is slowly becoming the world's most inexpensive armament.

In the United States, several different guidance systems were successfully developed during World War II for remotely and automatically controlling the flight path of bombs. Since then, developmental effort has been expended over the whole guided missile field. According to recent releases, this embraces at one end of the size scale small but extremely accurate

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air-to-air rockets, and at the other end, some intercontinental missiles such as the North American Aviation NAVAHO SM64 missile and the ATLAS SM65.

Owing to the fact that they need not carry their own oxidizer, jet engines are finding some application in guided missiles. Because of its greater speed, the ramjet will probably replace the turbojet in future designs. But the liquid-propellant rocket will undoubtedly continue to be the most effective and desirable power plant for high-flying, high speed missions. The United States has rocket engines which are more compact than the V-2 and which deliver significantly more thrust. Ramjet engines have powered test vehicles both here and in Britain. A number of guidance systems are available, some employing most ingenious concepts. New lightweight, high-strength, heat-resistant alloys, plastics, and cermets are in the process of development. Increasing use of digital computers simplifies systems engineering as results of more and more complex calculations become available. And some rather fantastic things are on the preliminary design boards throughout the nation. As a return on the multibillion-dollar investment in the U. S. guided missile program, definite progress will be seen next year and more progress in the years thereafter.

The next section discusses in very general terms some of the problems encountered in this field. These data and other information in this paper have been gathered from various sources, and this article does not necessarily represent the opinions of North American Aviation, Inc.

Guided Missiles—Types and Components

Table 1 presents a number of guided missile types, ranging from small air-to-air missiles, like the U. S. Falcon, to large intercontinental ballistic missiles, like the Snark. The Falcon costs about $10,000 and is powered by a solid propellant motor delivering 6000 lb of thrust. It contains automatic guidance equipment that homes on the enemy target. According to published reports, the Snark is the first American long-range guided missile to reach flight testing

Many of these guided missile types have several basic components in common, as shown in Table 2. The discussion presented here will, therefore, concern itself with component and component-development problems, and will be applicable, in a general way, to most of the missile systems. For the sake of discussion, we may divide the basic components of the guided missile system into nine fields of endeavor: payload; attitude control; structure; propulsion systems; target acquisition and identification systems; guidance systems; power supply systems; launching and handling equipment; and test equipment.

Payload

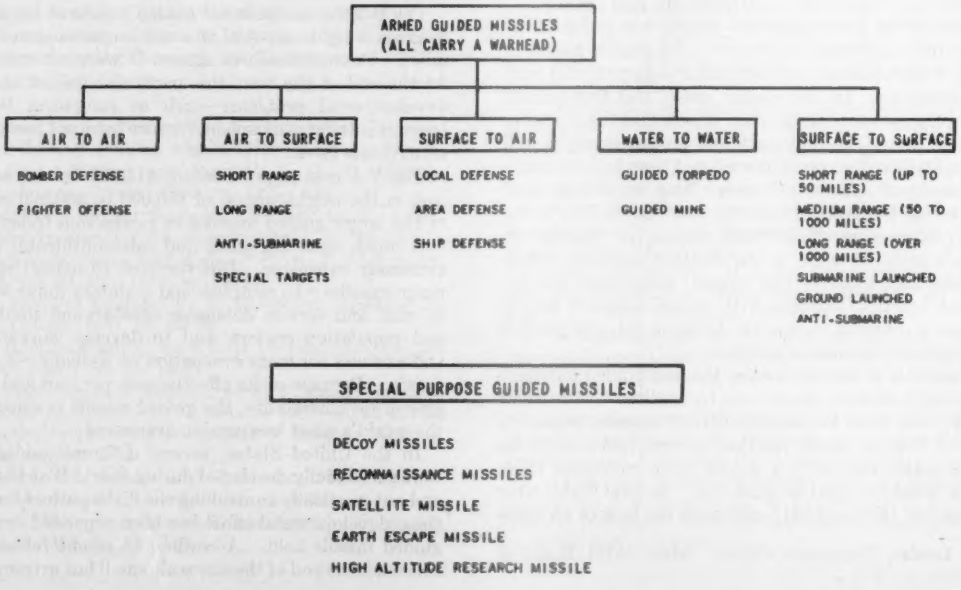
The payload of guided missiles encompasses a great many fields of science, depending on the mission of the missile itself. The missions may be reconnaissance (in which case the missiles must be fitted with complex observation mechanisms); research (in which case the missiles must carry a multitude of complex scientific instruments and recorders); or destruction (in which case the missiles carry fuzes and explosives).

In the latter case, the warheads vary in size and type to fit the requirements of a specific target. For example, armored targets will require a shaped-charge warhead to effect proper penetration of the protecting plate and will detonate immediately after impact. Strategic warheads will be, of course, vastly larger and may be detonated by a timing device of some complexity.

The nature of the fuze mechanism depends upon the mission, and may include a proximity triggering device, one or more provisions to permit safe handling and to prevent premature detonation (and occasionally to render the warhead harmless after passing an airborne target), and the actual trigger mechanism which activates the fuze at the proper instant of time. Some of these fuze mechanisms are as small and delicate as the workings of a precision-made watch. In recent years, considerable research has been expended, and complex, yet highly reliable fuzes are available for a variety of missile applications.

One significant departure from standard procedure, occasioned by the development of advanced fuzes, is that the warhead and fuze need no longer be in the missile nose—as was the case in many early guided missiles and in artillery shells. Today, stability considerations and guidance requirements often make it desirable to locate the warhead to the center of the missile. This has given considerable design flexibility to the missile systems and has, in a number of instances, improved guided-missile performance.

Table 1 Guided Missile Types



Altitude Control

It was only recently that many people were convinced of the impossibility of successfully breaking the sonic barrier with a man-carrying machine. That was accomplished less than six years ago. Today, high-speed sleds, powered by rocket engines, are traveling along steel tracks in the American desert at speeds faster than sound.

Today operating conditions are imposed on guided missiles which, before the last war, would have seemed fantastic. Missiles accelerate in a few seconds from sub to supersonic speeds. They travel at high Mach numbers through essentially airless space over 200 miles up; they approach targets at extreme angles of attack; and their aerodynamic controls surfaces must operate against corrosive jet blasts and air friction that would melt many conventional construction materials.

If large fins or tail surfaces are employed on the missile, it is usually possible to obtain a relatively stable aerodynamic configuration, although the design may resemble something out of a comic strip. A stable missile requires a high force from its controls to change its course. Jet vanes immersed in the rocket exhaust gas, gimbaled rocket engines, or large aerodynamic surfaces can be used to give these control moments. In some cases, particularly when wings are used, it is necessary to shift the wing location during flight in order to accommodate the radically shifting center of gravity. And often such accessories are, for one reason or another, undesirable and must be omitted. In many missiles the designer may have to tolerate a highly unstable system in order to satisy overriding considerations. When a missile is designed to have a small margin of stability, the control system must have a very fast response to prevent flight difficulties and maverick missiles.

The problem of initial stability is one of some consequence. Fixed fins, which seemed most promising, proved inadequate to control small armament rockets. During the first portion of powered flight, the side effect of wind against the fin surfaces was sufficient to deflect the missile to a nonreproducible trajectory. The situation was overcome by installing folding fins which opened only after the speed had increased. For larger missiles, jet vanes are often used to provide stability during the initial or hovering phase of flight.

For antiaircraft missiles, a cruciform wing and control surface configurations appear best suited to promote high maneuverability in all directions. However, the vortexes from the forward surfaces usually result in complex flow fields on the rearward surfaces and some unusual control force effects. With the aid of supersonic wind tunnels, considerable design advances have been made in the past few years, as the shock waves from supersonic jet planes daily testify.

Structure

Considerable progress, likewise, has been made over the last decades to evolve improved structural methods, advanced materials, and advanced design methods which will allow the use of low safety factors and lightweight construction. Weight saving is, particularly in missiles of high mass ratio, of primary importance. The high maneuverability required of guided missiles used against airborne targets greatly influence the tolerance requirements of the airframe structure and the alignment of the thrust axis. In some cases forward accelerations exceeding 100 g's and side accelerations exceeding 30 g's have been encountered. The general trend seems to be toward higher velocities, lighter weights, and more severe airframe requirements.

The aerodynamic heating of the surfaces in high-speed flight is an acute missile design problem. These stagnation temperatures appear to be increasing daily and may exceed several thousand degrees in long-range ballistic missiles. The re-entry of long-range missiles into the dense atmosphere,

Table 2 Components for Different Missiles

TYPE	AIR TO AIR	AIR TO SURFACE	SURFACE TO AIR	SURFACE TO SURFACE
PAYLOAD	WARHEAD (HEAVY OR LIGHT) WITH FUSE			
ALTITUDE CONTROL (STABILITY AND STEERING)	AERODYNAMIC SURFACES, JET VANES IN EXHAUST GASES, GIMBALLED THRUST CHAMBER			
	HIGHLY MANEUVERABLE	SLOW TURNS	HIGHLY MANEUVERABLE	SLOW PROGRAMMED TURNS
STRUCTURE	MATERIALS DEPEND ON ENVIRONMENT (SPEED, TEMPERATURE, CHEMICAL FUELS, ETC.)			
PROPULSION SYSTEM	ROCKET	ROCKET RAMJET TURBOJET	ROCKET RAMJET	ROCKET RAMJET TURBOJET
TARGET ACQUISITION AND IDENTIFICATION	INTELLIGENCE SYSTEM USUALLY IN LAUNCHING AIRCRAFT	SYSTEM IN MISSILE OR LAUNCHING AIRCRAFT	SEARCH RADAR SYSTEM	TARGET USUALLY PRE-SELECTED
GUIDANCE SYSTEM	IN MISSILE, LAUNCHING AIRCRAFT OR BOTH	IN MISSILE, LAUNCHING AIRCRAFT OR BOTH	ON SURFACE INSTALLATION IN MISSILE OR BOTH - LARGE TRAFFIC CAPACITY	IN SURFACE INSTALLATION, IN MISSILE OR BOTH
POWER SUPPLY	USUALLY SIMPLE STORED ENERGY	STORED ENERGY (PRESSURIZED GAS, ELECTRIC BATTERY) FOR SHORT DURATION AND SMALL MISSILES, TAKE-OFF FROM PROPULSION SYSTEM DURING POWERED FLIGHT AND AUXILIARY POWER UNIT FOR LARGER MISSILES		
LAUNCHING EQUIPMENT	AIRCRAFT INSTALLED, OFTEN RETRACTABLE	AIRCRAFT INSTALLED, OFTEN RETRACTABLE	LAUNCHING TRACK OR PLATFORM AND CONSIDERABLE MOBILE CALIBRATION AND CHECKOUT EQUIPMENT	LAUNCHING PLATFORM WITH CONSIDERABLE EXTRA CALIBRATION AND CHECKOUT EQUIPMENT
HANDLING EQUIPMENT	SIMPLE FOR SMALL MISSILES	COMPLEX FOR LARGE MISSILES	READINESS REQUIRES SPECIAL PROVISIONS	LARGE MISSILES TO BE ASSEMBLED IN FIELD

a problem which bothered the Germans, is still considered to be difficult. Several methods are under consideration. One involves slowing the missile by mechanical speed brakes. Another involves breaking the missile apart and permitting the warhead to float down on the target. And another involves protective coatings which will, bit by bit, burn away in the atmosphere.

The problem of separating the stages of a multistage missile is also an interesting one. The separation must be clean and accompanied by no side force. This has become an increasingly urgent structural consideration, which is difficult to simulate in laboratory tests. The problem was probably first encountered by the Germans during the latter part of World War II. For the separation of antiaircraft missiles from boosters, they provided for terminal thrust deflection through canted nozzles.

Propulsion Systems

Since rocket and ramjet propulsion systems are discussed in other articles in this issue, they will not be considered here in any detail. In general, it can be said that with the increasing need for high speeds and high altitudes, the rocket engine, both solid and liquid propellant, is becoming the most commons means of propulsion for guided missiles. The second most common is the ramjet, which is considered optimum in some applications. The usefulness of the turbojet seems to be limited by its low speeds.

For airborne targets, it is essential that the guided air-to-air or ground-to-air missile reach its destination quickly. Emphasis here is on very short flight time and very short rocket firing duration. Solid propellants can be used advantageously in most of these weapons; but the liquid propellant engine sometimes is a superior power plant in the larger missiles.

Guidance requirements may, in some applications, place severe limitations on the performance accuracy of the propulsion system, unless such control accommodates a number of inherent variations: such as the time required to reach full thrust, the tolerance on the rated thrust, or the performance variation with temperature.

Target Acquisition and Identification Systems

All guided missiles need a system which will identify and locate the target. In systems employed against airborne targets, a search radar or an optical device furnishes information for general readiness and the instructions to launch. In systems against ground targets, accurate maps and preselected destinations provide the information on the target location. In aircraft defense systems, an additional device is needed to distinguish between friend and foe, so that the aircraft defense will not shoot down friendly airplanes.

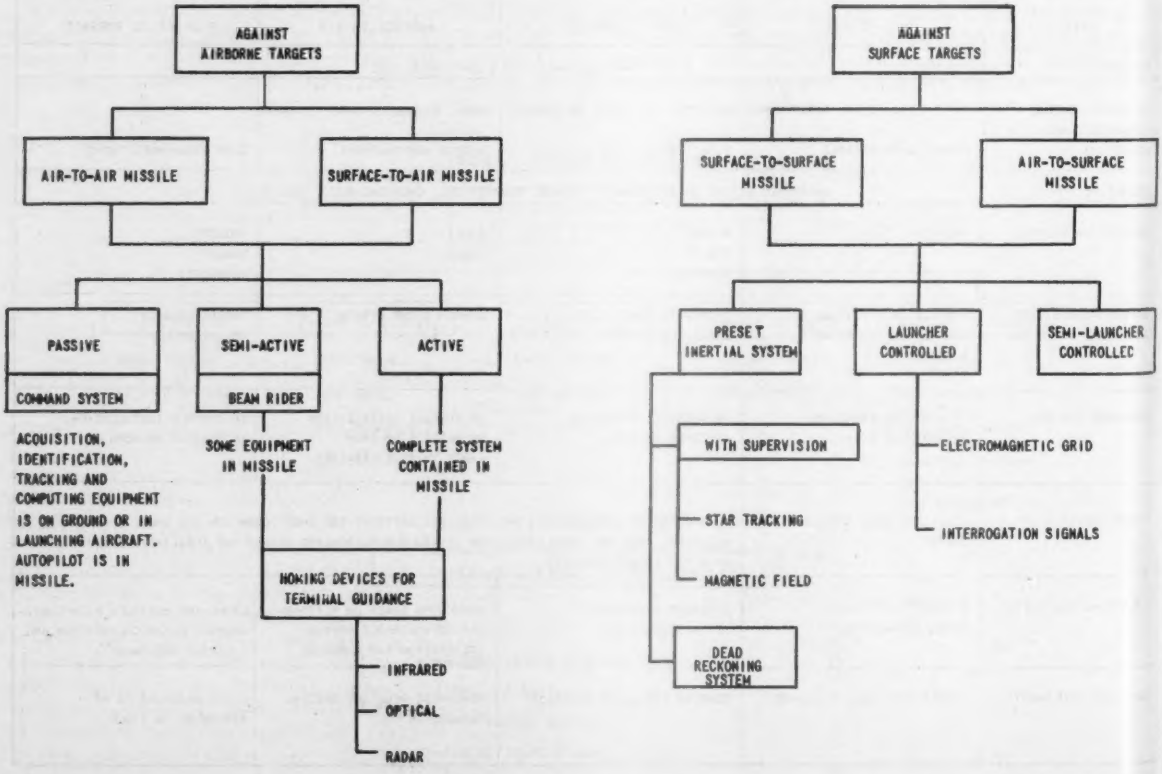
Guidance Systems

The degree of complexity of the electrical circuits for some modern guided missiles can well be imagined. Much of this equipment is used in the guidance system. The progress in electronics during the past decade, the development of transistors and printed circuits—not to mention the refinement of radar equipment—are employed to an advantage in today's guidance systems. Although we have made considerable progress, much work remains to be done. New approaches may be required.

Guidance systems have been a major stumbling block in the development of the missiles. This was one area where the Germans, for instance, were able to make little progress during the war, and in comparison, their airframes and propulsion systems were highly advanced.

Depending on the mission, durations, and the general operating philosophy, guidance systems come in many different forms (see Table 3). It is perhaps best to discuss two fundamental types: those against air targets and those against ground targets.

Table 3 Guidance Systems



Guidance systems in principle must take information on the location of the target, on the predicted location of a moving target, information on the location of the missile itself, and information on some referenced coordinate system. This information is fed into a computer to determine the corrections in the flight path of the missile so that it will land on the intended target. Missile position correction is then transmitted through an autopilot and the power control system of the missile, where in turn it is transformed into a suitable control force. Aerodynamic surfaces, gimbaled thrust units, or jet vane systems may be employed to provide directional responses.

There are three types of guidance systems for use against air targets. The first is a passive system often called the Command System, in which the missile carries very little guidance equipment. The radars and computers—the nervous system, that is—are all on the ground or in the controlling airplane. They identify and track both the target and missile by means of radars and visual tracking devices, log the courses of each, and issue instructions to the missile itself. In the second type, the Active Guidance System, almost all the equipment for locating the position of the missile, for computing the corrections, and for terminal guidance are located within the missile airframe. A third type, the Semi-Active Guidance System, falls in between these two. Here the guidance system is divided between the missile equipment and the launching station equipment. The beam rider system is an example. The missile intercepts and follows a narrow-coded radio beam automatically locked into the target by radar.

Homing devices are employed (usually in the second and third type missile) for obtaining final corrections for the last or "terminal" portion of the approach. Their effective range is limited. Homing devices are "visual" detectors. They may operate on infrared or magnetic beams emitted by the target (passive homing); on self-emitted radar beams (active homing); or on beams projected from the ground to "illuminate" the target (semi-active homing).

For missiles intended for use against ground targets, the guidance system is fundamentally different. In this case it is necessary to compare the missile flight path with a predicted flight path and to make accurate, incremental corrections in the trajectory throughout powered flight. Except for short-range missiles intended against near-by ground targets, the guidance system is usually fully contained within the flying vehicle. The accuracy of this guidance system can be improved, particularly for long ranges, if reference coordinate information can be fed into the guidance computer. This coordinate may come from a directional radio signal or, through a missile-mounted telescope, from the location of a star. An autopilot is required to maintain flight stability. Geodetic errors (that is, errors caused by the earth not being perfectly round, caused by inaccuracies in the maps, etc.), instrument errors, gravity changes, time drift of gyroscopes, and air currents all combine to detract from the accuracy of the missile. Even so, the missiles are far more accurate than, say, the V-2; and technological advances each year contribute measurably to improvements—even as technological advances in warheads render accuracy of less and less importance.

Power Supply Systems

An energy source is required for implementing the intelligence furnished by the guidance system. Hydraulic, electrical, pneumatic, and mechanical energy sources and power supply systems have been and can be used to actuate the control surfaces and control mechanisms. The exact choice of specific systems depends upon the application and on such factors as missile space, duration, readiness, speed of response, and environment. Generally, a fast system response is required to actuate controls; i.e., the power supply system must be capable of operating with high frequency input signals. For short-duration applications, a bottle of compressed gas or a small storage battery is often adequate. For long-duration applications, a complex auxiliary power unit is usually indicated. Unusual power supply methods can be developed involving chemical gas generators as energy sources and rocket-driven auxiliary power units suitable for operation outside the atmosphere.

Launching and Handling Equipment

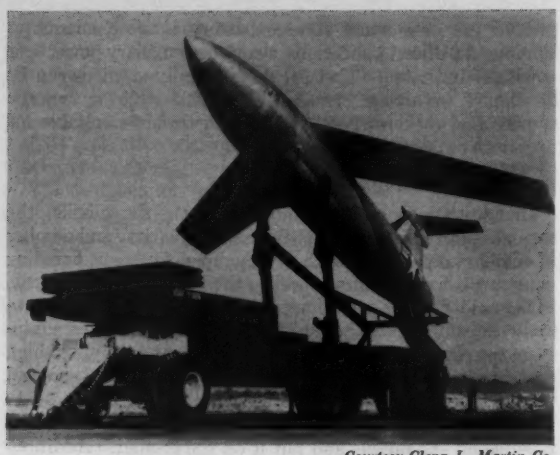
In addition to building and developing the missile, the manufacturer must, today, provide a large variety and number of auxiliary equipment, such as launching platforms, handling equipment, fixtures for assembling the warhead to the missile in the field, storage provisions, fueling equipment, calibration and checkout devices, ground power supply generation equipment for electricity at several voltages, ground supply of high pressure liquids and gases, a timing reference signal, ground radar equipment, supply, storage, and repair facilities—to name but a few. The general tendency is to take everything possible off the missile and put it on the ground. Additionally, as the missile itself becomes more complex, the ground service requirements likewise increases. Most of this equipment is, however, unlike the missile, reuseable but, like test facilities, requires additional expenditure for normal maintenance and to avoid obsolescence. It is interesting, for example, that the NIKE antiaircraft missile requires some 64 different major items of equipment (both mobile and fixed) to serve a military battery. In addition, other equipment is often necessary to recondition missiles while they are stored.

Test Equipment

During the development of a guided missile, a huge number of new problems require engineering solutions of an unusual type, accuracy, and character. For example, the development of a telemetering system is a useful byproduct of the guided missile art. The development of additional unique equipment can be illustrated by specialized hypersonic wind tunnels, high frequency response pressure pickups, or high-temperature measuring devices. A complex and varied technology is required to support this test effort. The construction of specialized equipment frequently taxes the ingenuity of the designer and engineer. Some of this test equipment results in the extension of fundamental physical knowledge; and frequently, too, reveals the need for the development of higher-quality commercial components. The results of this activity are fed back to industry, and general product improvement follows. Highly reliable lightweight solenoid valves, or miniaturized radio components, for instance, developed especially in response to the needs of missile systems are now available to industry generally and find their way into commercial applications. The guided missile has, therefore, created in its wake not only auxiliary and supplementary industry but also superior industrial components.

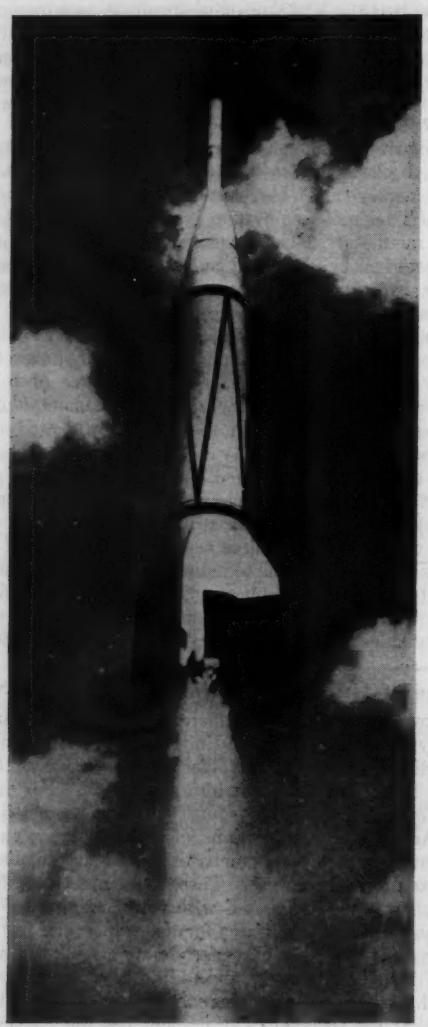
Status of Guided Missiles in the United States

There are now over 30 different guided missile projects actively being pursued in the United States. All branches of the military service are involved in this activity. Several missile types have been put into production. For example, some 13 major cities in this country are now protected by the U. S. Army NIKE installations, of which there are some 100 different sites. Corporal bombardment missiles are also being converted for military use. These will consist essentially of the high-altitude Corporal E with modifications such as the substitution of delta surfaces for the trapezoidal fins. Two squadrons of MATADOR surface-to-surface missiles are now on active duty in Germany, and additional squadrons are being trained. It was recently announced by the Defense Department that the Ordnance Department has the REDSTONE surface-to-surface missile produced by the Chrysler Corporation. The HONEST JOHN (which is really an unguided missile) has been put into service in the U. S. Field Artillery in Europe. The TERRIER antiaircraft missile and the



Courtesy Glenn L. Martin Co.

The MATADOR surface-to-surface turbojet-powered missile on its mobile launching stand. Solid propellant booster rocket is used to aid take-off



U. S. Army Photo

Bumper-WAC two-stage research missile has reached altitudes of over 250 miles. The V-2 rocket is used as the first stage and the WAC for the second stage which is started and separated at altitude

SPARROW air-to-air missile are being put into service with the U. S. Navy after two years of intensive development testing. A variety of bomber and fighter missile armament systems are available to the Air Force. Other missiles, of all different sorts, are on the drawingboards and in the development stage.

This initial production is the payoff to a national investment of over $5 billion and the reward for years of patient technical effort. More production and better missiles are to come. A detailed account of U. S. guided missiles, in so far as it has been found in the literature, can be obtained from K. W. Gatland's book "Development of the Guided Missiles" and other references in the bibliography presented at the end of this paper.

The recently announced satellite program is the heir to the technical developments of large surface-to-surface guided missiles. It is hoped that more and more of this store of technical knowledge will be put to use for peaceful purposes in the future.

U. S. Army Photo

CORPORAL surface-to-surface missile with erecting equipment

Hughes Aircraft Co.

FALCON air-to-air guided missile is small and light enough to be easily lifted by two men

U. S. Army Photo

The NIKE surface-to-air guided missile, shown here on its launching rail, protects more than 13 U. S. cities against air attack. It has a large, separate solid propellant booster, which separates from the guided missile

One of several types of British Research Missiles uses solid propellant booster rockets clustered around the missile. Nozzles are slightly canted and boosters separate simultaneously

Status of Foreign Missiles

Relatively little is known about the guided missile advances made by foreign countries. The British, who have recently published a White Paper on the subject, admitted to having fired more than 1500 missiles at their two launching ranges (one in Wales and one in Australia). They are concentrating on antiaircraft missiles, and two such missiles have been unveiled. Having captured few German scientists at the end of World War II, they are apparently largely ignoring German experience. The use of a side-mounted booster arrangement and the clever application of ramjets give evidence of independent development thinking. The White Paper also mentioned a long-range missile project, whose mission will exceed that of the German A-10 design—the uncompleted missile which was supposed to deliver a payload on New York. Some 100 companies are now engaged in the billion-dollar British missile effort.

The French have concentrated on research missiles which can be converted to operational weapons. They, too, are developing missiles which are small in size and therefore relatively low in cost.

The Swiss have developed a clever antiaircraft liquid-propellant rocket system, and minor efforts are also under way in countries such as Italy, Sweden, the Netherlands, and Canada.

The USSR has a guided missile program which apparently is very extensive. Their field of activity encompasses long-range ballistic missiles, refinements of German aircraft missiles, and development of submarine launched surface-to-surface missiles.

General Guided Missile System Problems

Over the past decade a number of problems have presented themselves in the development, production, and military use of complex weapons such as guided missiles. One of the characteristics of any rapidly developing technical field is almost continually *changing requirements*. Many a missile which is intended to fulfill a specific mission has become obsolete before its development was completed. With airplanes flying higher and faster and with frequent changes in military tactics, the design objectives for specific missiles must be revised to fit the new requirements. For example, an antiaircraft missile system may be very different if it is designed to cope with a single target airplane or a squadron of target airplanes. Equipment that can provide effective defense against subsonic aircraft is practically useless against supersonic missiles. As bomber defensive armament improves, fighter planes must be able to release their fire power at ever increasing distances. The defensive and offensive

HONEST JOHN surface-to-surface missile, shown here on its adjustable, mobile launcher, is now in service with the U. S. Army Artillery overseas

requirements are closely interrelated: a change in one occasions a corresponding change in the other. The ultimate missile or defense today will become obsolete tomorrow.

Even assuming a missile is designed for conditions which, it is assumed, will prevail five or ten years from now, there is always the possibility that new developments may make an alternate missile system superior. In view of the rapid expansion of world technology, firm military decisions are difficult, and appropriations must allow for the possibility of unfruitful and extremely expensive projects.

The best compromise solution possible, of course, is to design missile systems with considerable *inherent flexibility*. A basic missile type may be emerging, in which provisions are made for the substitution of one warhead for another, and in which range may be varied to accommodate specific missions by changing the thrust of the missile booster.

The design philosophy of guided missiles is another area which has not been fully explored. The question of *reliability versus complexity* is one to which no definitive answer can be given. Unfortunately, most missile systems have little redundancy—superfluous parallel-circuit type parts have already been designed out of them; they are essentially a series-type circuit of complex components. The malfunction of one small component in this series arrangement can mean the abortion of the mission. Even the simplest guided missile is very complex. Since there are few duplicating functions, little improvement can be made short of a major design reorientation. Simplicity cannot, therefore, usually be achieved except at the expense of accuracy and of the capability of the missile to fulfill its mission satisfactorily. For example, the NIKE missile system requires 1,500,000 parts. Nothing less than a revolutionary advance in guided missile design (which does not seem in prospect) would permit simplification to the degree that there would be a noticeable effect on system reliability.

Another design facet concerns the unusual extremes of *environment* through which guided missiles must operate. Aside from the environmental conditions encountered during its normal flight (extreme temperatures, high accelerations, severe vibration, or inverted attitude), a modern missile is subjected to harsh preliminary tests; for example, small missiles are dropped from an elevation of several feet to a concrete pad, and most missiles are subjected to high humidities, and their components are vibrated on special shake tables.

Maintaining the missile in *constant readiness* for operational use is, naturally, of critical concern to the national defense effort. This requires continuous alertness and maintenance by specialized and specially trained personnel and sample testing of a certain portion of the deliverable missiles. This preparedness is expensive and, according to some sources, the maintenance of a missile system from two to four years is equal to the initial capital cost. A new emphasis on design therefore must be for simple maintenance and servicing, even to some degree at the expense of performance efficiency and weight reduction.

The lack of adequate *feedback information* in the development and refinement of guided missiles is an obvious but often overlooked problem of this new art. In a conventional technical device, such as an automobile or an airplane, it is possible to perform many tests on the article under investigation before it wears out or fails. In guided missiles, the article is usually destroyed in the first experimental flight. Therefore, it is necessary to resort to simulated tests in which flight environmental conditions are approximated through cleverly devised test equipment. Since any simulation is never complete in all of its details, a missile can only be properly tested when it fulfills its intended mission. Even here the amount of data that is obtained is very meager and is biased through complex instrumentation and telemetering installations. Development testing is therefore very expensive, and the development engineer obtains relatively little information on which to base his decisions for modifications and improvements.

Another very difficult subject is the assessment of the *actual worth* or value of a particular guided missile to the nation. Here such factors as the damage potential, the portion of the total national effort that has to go into developing and producing the missile, the moral and psychological effect on friend and enemy, its compatibility with existing equipment and available facilities, the operating life of the complex device, the cost of its operation, its logistic value—all these and more have to be carefully weighed and optimized. It is extremely difficult to measure many of these factors, and it requires profound judgment to compare one feasible missile system with another. The military men who have to bear the responsibility for making these decisions do not have an easy task.

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Twenty-Five Years of Progress Toward Space Flight

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BY THE year 1930, in which the AMERICAN ROCKET SOCIETY (then called the American Interplanetary Society) was established, the advance toward space flight had entered its second phase, the period of experimental preparation.

Era of Theory

In the first phase, corresponding roughly to the first quarter of the twentieth century, the theoretical basis of rocket flight was worked out. The task was accomplished by three men working independently in three different countries. The three had much in common—they were teachers, one at a small university, the other two in secondary schools.[2] Each one pondered the problem for many years before committing his findings to publication. But what is most important, all three were motivated by the desire to explore interplanetary space and presented their findings with conviction, even though they were regarded by most of their contemporaries as prophetic dreamers. The men and their works are now well known. They are:

Ziolkovsky ("The Exploration of Cosmic Space by Reaction Machines"), 1903

Goddard ("A Method of Reaching Extreme Altitudes"), 1919

Oberth ("The Rocket Into Interplanetary Space"), 1923.

Any one of these three publications, had it been widely read and accepted, would have sufficed to lay the groundwork for space travel, because each man clearly understood and asserted the following fundamental concepts:

1. That escape from the earth is possible by the application of a moderate acceleration over a substantial period of time—at least several minutes.
2. That such acceleration can be produced in a vacuum by a rocket.
3. That the rocket must (a) have high thermal efficiency (i.e., high velocity of the ejected matter), and (b) consist mainly of propellant material (i.e., have a high ratio of fuel weight to total weight).
4. That high thermal efficiency would be obtained most readily from the chemical combustion of liquid fuels.

Ziolkovsky (1)[3] started by examining Jules Verne's cannon[4] and also the balloon as a means of reaching very high altitudes. Both approaches died quickly under mathematical analysis. He proceeded next to the rocket and developed the fundamental equation of rocket action in free space. Realizing that energetic fuels were required, he determined from thermochemical calculations the heat release of various liquid combinations. When he computed the velocity that could be attained, in theory at least, he realized it was sufficient for escape from the earth.

Goddard (2), alone of the three, proceeded from experiment to theory. Using smokeless powder in a heavy-walled steel combustion chamber, he produced a jet velocity of almost 8000 ft per sec, a sevenfold improvement over ordinary rockets and the highest velocity of matter attained up to that time outside of electrical discharge tubes. Also, he proved by tests in a vacuum that a rocket does not produce its force by pushing on the air behind it, a fact he knew from basic physics but that he felt had to be demonstrated. He observed correctly that the jet velocity was greater in a vacuum, but he attributed it erroneously to more efficient ignition. Although Goddard did not turn to liquid fuels until after his basic paper was published, he achieved the first flight of a liquid rocket, an event that took place on March 16, 1926. Goddard (3) continued his experiments for more than two decades during which time he developed, in rudimentary form, almost every component of modern rocketry. Not one of his components would be considered reliable by present-day standards; realizing the prodigious task he had set out to accomplish, he would repeatedly add a new component before perfecting the previous one. In retrospect, it appears that Goddard was attempting, single-handed, to encompass the entire field of liquid-rocket development, a task that would eventually tax the abilities of thousands of engineers and scientists.

Oberth (4), in his treatise, gave the most complete theoretical analysis and carried it farther into the realm of space travel than either of the others. He stated at the outset the four propositions he would attempt to prove:

1. Considering the present state of science and technology, it is possible to build machines that could rise beyond the atmosphere.
2. After further development these machines will be able to attain such velocities that, left undisturbed in the depths of outer space, they will not fall back to the earth and will even be able to leave the zone of terrestrial attraction.
3. These machines could be constructed so as to transport human beings, probably without damage to their health.
4. Under certain economic conditions, the construction of such machines might be profitable.

Oberth began by developing the theory of the liquid rocket and describing its construction. He proceeded to discuss applications of the rocket, first as a high-altitude sounding vehicle, then as an earth satellite, and finally as a space ship for interplanetary travel. He developed the concept of synergic (minimum energy) ascent trajectories. Without doubt, almost every later book on space flight owes much to Oberth's encompassing study.

Era of Experiment

The second quarter-century period, that of experimental preparation, may be viewed as starting with the first flight of a liquid-fueled rocket launched by Goddard on March 16, 1926, at Auburn, Mass. His small tubular structure, ungainly in appearance, flew for a scant 2.5 sec and attained a speed of only 60 mph. Goddard continued his experiments, mainly at his small desert station in New Mexico, until in 1935 he achieved an altitude of 7500 ft with a gyroscope-stabilized rocket that resembled in miniature the giant rockets to come—the V-2 and Viking.

In Europe, the early experimental work was done mainly by amateurs who in 1927 banded together in the German Space-Flight Society, the Verein für Raumschiffahrt (5). Early members of VfR included some of the pioneers of rocketry—Winkler, Valier, Oberth, Hohmann, and later, Nikolai Rynin and Robert Esnault-Pelterie. The society undertook a sensible program to develop a small, reliable liquid-rocket motor, called appropriately "Minimum-rakete" (Mirak, for short). The group made good progress, in the

[1] Technical Director of Project Vanguard. Mem. ARS Board of Directors.

[2] One, Herman Oberth, became a teacher after his fundamental work had been completed.

[3] Numbers in parentheses indicate References at end of paper.

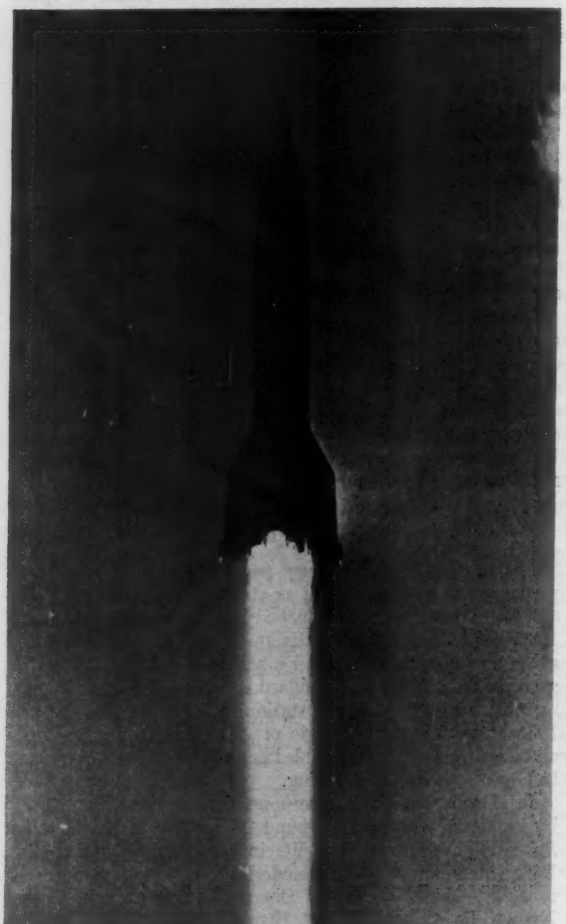
[4] Jules Verne, in his novel "From the Earth to the Moon," projected his space ship to escape velocity, from a long cannon sunk in the ground.

Courtesy G. Edward Pendray

Robert H. Goddard at Auburn, Mass., on March 16, 1926, with his liquid-oxygen gasoline rocket in the frame from which it was fired that day

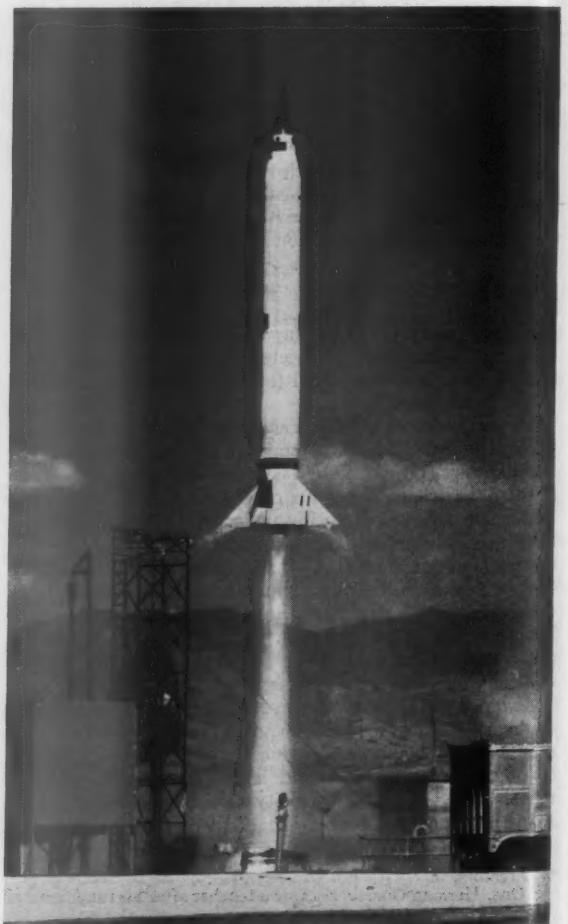
Courtesy G. Edward Pendray

Pierce and Pendray, co-designers, inserting the parachute before a demonstration of ARS Rocket No. 1 at New York University, Feb. 19, 1932



Official U.S. Navy Photograph

A V-2 instrumented for upper air research rises from White Sands Proving Ground, N. Mex.



Official U.S. Navy Photograph

Take-off of Viking 11, which rose 158 miles and established the altitude record for single stage rockets

course of several hundred static firings and flights, before its dissolution in 1933. One of the Society's members, Wernher von Braun, later became head of the great wartime rocket laboratories at Peenemunde, where the German Army developed the V-2.

It is perhaps ironical, but certainly understandable, that the largest single engineering advance toward space flight, the V-2 rocket, should have been developed under the impetus of war. Only through the efforts of thousands of engineers and technicians, and the application of vast facilities and funds, could the development of so large a rocket be accomplished at so early a time. The V-2's development started in 1936, but its designers had to proceed through several models of smaller size before attempting a 45-ft high, 14-ton rocket. The first V-2 was launched in 1942 and by the end of World War II, over 3000 had been built and fired. The V-2 was a material embodiment of Oberth's ideas, and although he conceived the liquid rocket as a vehicle for space travel, he also foresaw its possible use as a bombardment weapon.

After the war the V-2 was brought to the United States where it saw extensive employment as an upper-air research vehicle. In its best flight it reached a height of 132 miles, and on another occasion was a booster for the two-stage Bumper-Wac that established a 250-mile altitude record.

American Interplanetary Society

On April 4, 1930, about a dozen persons met in New York City to form a society for the "promotion of interest in and experimentation toward interplanetary expeditions and travel." The group, which then called itself the American Interplanetary Society, was subsequently to become the AMERICAN ROCKET SOCIETY. Inspired by the work of the VfR in Germany, the American Society began experimenting with small rocket motors and vehicles. Their first flight is described by G. Edward Pendray in the Society's official organ *Astronautics* for May 1933:

"Experimental Rocket No. 2 of the American Interplanetary Society was shot at 20 minutes past eleven o'clock, Sunday, May 14. It reached an altitude of approximately 250 feet after firing a trifle more than 2 seconds. At that height the flight was brought to an abrupt end by the bursting of the oxygen tank.

"Despite this mishap, the experiment must be considered a success. It proved without doubt the efficacy of the rocket motor developed by the Society, and gave us our first actual experience with the firing of a liquid fuel rocket."

The AIS continued to design and test small rockets until 1939 when, with the outbreak of war in Europe, the principal members turned their efforts to the defense of their country. Prominent among the early AIS experimenters, in addition to Pendray, were Franklin Pierce, Bernard Smith, John Shesta, James Wyld, and Alfred Africano (6).

After the war the major activity leading to space flight took place in the United States in the form of upper-air research with instruments carried in rockets. In a continuing program, scientists from government laboratories and universities explored the upper atmosphere using, at first, captured V-2 rockets and later, as they became available, Aerobees and Vikings. A complete survey of upper-air research techniques and data is found in Newell's "Rocket Research in the Upper Atmosphere." A few of the more important accomplishments of this program are noted here. Knowledge of the pressure, temperature, density, and ionic content of the atmosphere has been extended up to 135 miles by direct measurements. The solar spectrum has been recorded in the far ultraviolet. X rays have been detected in solar radiation and their role in the formation of the ionosphere has been postulated. The number and the mass distribution of primary cosmic rays have been recorded in emulsions carried aloft in rockets. Small animals, monkeys and mice, were sent aloft and their physiological reactions observed during a period of weightlessness. For nine years man has been exploring the frontier to space as a prelude to flight beyond the atmosphere.

Wac-Corporal, Aerobee, Viking

Actually, the first practical sounding rocket was the Wac Corporal, whose development began in 1944 at the California Institute of Technology's Jet Propulsion Laboratory. JPL, started in 1936 by Theodore von Kármán and a few graduate students, has grown to be one of the foremost centers of rocket research in the world, and in this capacity has contributed greatly to the advancement of space flight.

The Aerobee, also designed specifically as a sounding rocket, was at first an enlarged version of the Wac Corporal. Like its predecessor, it used nitric acid and aniline as propellants. The Aerobee has been improved by its producer, the Aerojet-General Corporation—the most recent version, called Aerobee-Hi, is aimed at a peak altitude of 180 miles. This rocket will be used extensively during the forthcoming International Geophysical Year.

The Navy-Martin Viking, the first large rocket built for upper-air research, holds the present altitude record (158 miles) for single-stage rockets. Started in 1946, Viking, in addition to its instrument-carrying function, has been a test vehicle for new techniques in rocketry including the gimbaled motor, attitude control by means of jets, propellant-level sensing, and many innovations in lightweight construction. The story of Viking's development has been described elsewhere by the author (7).

Probably the most intensive investigation of the upper atmosphere yet attempted will occur during the International Geophysical Year, the interval from July 1, 1957, to December 31, 1958. Of the forty participating nations, the United States and France have announced definite plans for high-altitude rocket programs. In the United States program, 45 Aerobees will be fired at Churchill, Canada, and in New Mexico. Among the experiments to be performed will be measurement of ionospheric charge densities and the earth's magnetic field; determination of atmospheric structure, composition, and winds; auroreal and aerglow studies; and measurement of solar radiation. More than a hundred smaller rockets will be fired at various locations from the equator to the polar regions in synoptic studies of cosmic rays, auroral particles, and solar radiation during solar flares (8).

No account of the progress toward space flight would be complete without noting the important work done by rocket and space-flight societies in promoting interest, stimulating research, and providing in their journals and meetings a forum for the presentation of papers and the discussion of space-flight problems. There are societies devoted to rocketry and space flight in twenty-three countries and most of these are members of the International Astronautical Federation (see list in the Appendix). The IAF meets in an annual congress at which leading scientists and engineers present papers on space flight and its allied fields. The most recent Congress in Copenhagen, Denmark, August 1955, was devoted to problems associated with the unmanned, earth satellite.

Although the literature of space flight contains many proposals and vehicle designs for flights to the moon and the near planets (9), the major interest in the past few years has centered upon the first realizable step to space—the small, instrumented satellite. A theoretical study (10) of the problem by Seifert, Mills, and Summerfield appeared in 1947 in the *American Journal of Physics*. Gatland, Kunesch, and Dixon (11) laid emphasis on the structural design of minimum satellite vehicles in 1951. Stehling (12) showed recently that the vehicle's size could be reduced substantially if it were possible to launch it at altitude from a balloon. Others have dealt with experiments that could be performed in a satellite and the difficult problem of observing it from the ground.

Scientific Earth Satellite

At its Rome meeting in October 1954, the Special Committee for the International Geophysical Year adopted a resolution recommending the construction of a small, scientific satellite. The AMERICAN ROCKET SOCIETY, in November 1954, presented to the National Science Foundation a proposal entitled "On the Utility of an Artificial Unmanned Earth Satellite." The ARS proposal included papers by six leading scientists who, collectively, described broad fields of utility for the instrumented satellite. Among the sciences that would be advanced by an instrumented satellite were astronomy, astrophysics, biology, communication, geodesy, geophysics, and meteorology.

The welcome news to all advocates of space flight was received on July 29, 1955. On that date, the White House, the National Science Foundation, the National Academy of Sciences, and the Department of Defense announced plans for the construction of an earth satellite vehicle to be launched by the United States during the International Geophysical Year. In all of these announcements it was made clear that the United States would share its scientific findings with all nations and that scientists everywhere would be invited to monitor and observe the orbiting vehicle.

The satellite announcement marks the end of the second quarter-century of progress toward space flight, the period of experimental preparation. The third and next interval may rightly be called the era of accomplishment. I predict that the next twenty-five years will produce satellite vehicles of increasing size and utility and that all of this work will lead, eventually, to manned flight in outer space.

APPENDIX

Currently the following national rocket and astronautical societies are members of the International Astronautical Federation:

Argentina	Sociedad Argentina Interplanetaria The University of Cuyo (Affiliate Member)
Austria	Oesterreichische Gesellschaft fuer Weltraumforschung
Brazil	Sociedade Interplanetaria Brasileira
Chile	Sociedad Interplanetaria Chilena
Denmark	Dansk Interplanetarisk Selskab
Egypt	Association Egyptienne Astronautique
Germany	Gesellschaft fuer Weltraumforschung Deutsches Raketen- und Raumfahrt-Museum e.V.
Great Britain	British Interplanetary Society
Italy	Associazione Italiana Razzi
Japan	Japanese Astronautical Society
Jugoslavia	Astronauticko Drustvo
Netherlands	Nederlandse Vereniging voor Ruimtevaart
Norway	Norsk Astronautisk Forening
Spain	Agrupacion Astronautica Espanola
Sweden	Svensk Interplanetarisk Selskap
Switzerland	Schweizerische Astronautische Arbeitsgemeinschaft
Union of South Africa	South African Interplanetary Society
United States	American Rocket Society American Astronautical Society

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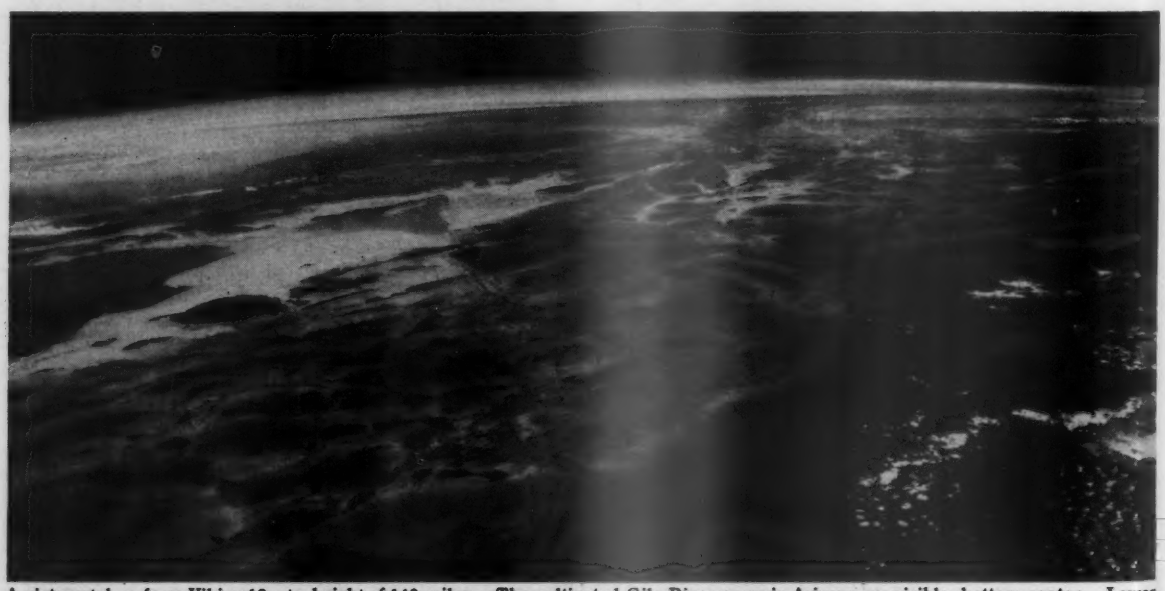

A picture taken from Viking 12, at a height of 143 miles. The cultivated Gila River areas in Arizona are visible, bottom center. Lower California at left; beyond it the Pacific extends to the horizon, 1700 miles distant

International Cooperation in Rocketry and Astronautics

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Introduction

IN this brief recountal of the efforts human beings and their private and public associations and governments have made to cooperate in the exchange of ideas and achievements in the fields of rocketry and astronautics, we have confined our discussion to five areas of such activities; namely, (1) between individual workers and societies; (2) by the establishment of awards and other honors; (3) by friendly contests and demonstrations; (4) through nongovernmental international organizations; and (5) through official channels and governmental organizations.

Cooperation in any aspect of rocketry did not exist prior to the twentieth century, and substantial developments did not occur until the 1930's. Rockets were weapons and the military guarded their rocket secrets. In the early days the difficulties of travel and the lack of communications further retarded the dissemination of data on rockets. For example, it took eight years for the news to reach Arabia that the Chinese had employed rockets to defeat Mongolian invaders in 1232 A.D. When Indian natives defeated British colonial troops at Seringapatam, the British were years in developing a rocket similar to those used by the natives. As an ordnance piece the rocket lost caste after Copenhagen and the War of 1812 and did not come back into its own for much more than a century. Late in the nineteenth century, however, world interest in the *peaceful* application of rockets to interplanetary travel was engendered by the "Jules Verne" type of novel in France (although Verne used cannons for space propulsion, as during his life rockets were in disrepute) and by science fiction in other nations, notably the rash of German books appearing after 1897.

The foregoing comments reveal that we really are discussing two distinct realms of the spectra of engineering and science which, while not parallel, are also not disparate—we refer to the rocket qua rocket (a form of propulsive device) and to astronautics, a term which has not been fully defined, but which we will assume to cover generally the science of space flight in all aspects. Within the framework of this paper we do not have the space constantly to distinguish between rocketry as such and astronautics, but we are not deeply concerned because we have yet to meet a rocket man who is not essentially an astronaut.

We have pointed out that international cooperation in any appreciable form is really the development of the past thirty to forty years. Nevertheless, in that period of time a great number of distinguished people and important organizations have participated in the activity. We can only mention a fraction of these by name, and it is all too certain that many of the most important will not be mentioned, and for this we express our regret.

I

During the first three decades of the twentieth century the great rocket pioneers earnestly undertook theoretical formulations of rocket and astronautical projects. Hermann Oberth of Rumania, Konstantin Ziolkovsky of Russia, Hermann Noordung of Austria, Walter Hohmann of Germany, Robert Esnault-Pelterie of France, Robert H. Goddard of the United States, and many other eminent engineers, scientists, and industrial experimenters, published basic studies that led to the great mass of literature and to the extensive experimentation which burst forth in 1930, and were interrupted only by World War II, and which underly our present-day rocket knowledge.

Many of the pre-1930 pioneers exchanged letters and on a few occasions visited one another. Exceptions were Ziolkovsky, who remained in seclusion in Russia where he wrote "Space Investigations by Means of Propulsive Space Ships" (1914) and "A Rocket Into Cosmic Space" (1924), but because he understood Russian alone he was unacquainted with the West, and the Western pioneers did not understand Russian so they were not acquainted with Ziolkovsky; and Goddard, himself, who was working tirelessly on the actual rocket hardware, while theorizing, and by 1926 had made the world's first successful liquid propellant rocket, but who was extremely prudent about disseminating information. It is now interesting to read the old publications of the present ARS[2] in which writers indicate in the 1930's that it was easier to obtain an interchange of information from the German rocketeers than from Dr. Goddard. The writer was a devotee at his shrine but was never received at Goddard's Annapolis installation. Looking back, it is now apparent that Dr. Goddard was absolutely correct. He had more to offer than he had to receive by way of an interchange of information in the particular field in which he worked. He knew the theory and was conquering the hardware. One of the splendid pronouncements of this era was the statement contained in a letter by Oberth to Goddard in 1922. With respect to space flight, he said, ". . .I think that only by common work of the scholars of all nations can be solved this great problem." If he had lived beyond World War II we are certain Goddard would be in the forefront of those advocating space flight.

The first common forum for astronauts in all nations was established in Germany in 1927—the Society for Space Travel [VfR]. The Russians may dispute this statement, as announcement was made in 1926 of a "World Center for All Inventors and Scientists" which was somehow integrated with reaction research societies in Moscow and Leningrad. No evidence is available, however, that this was more than a paper project, and short lived at that. In any event, the German society grew very rapidly. Five hundred members from Germany, Austria, Russia, and France joined the first year. Similar societies also sprang up in other countries. In those days, membership in such societies did not improve one's professional standing, and much effort of the societies was devoted to proving to the public that astronautics was a science which could be pursued by sane men.

While the societies were engaged with this and more theoretical pursuits, the Austrian, Max Valier, startled his fellow members of the VfR, including Oberth, by a spectacular use of an improvised rocket automobile powered by powder charges. He also arranged a rocket mail delivery. Opel

[1] General Counsel ARS; Mem. ARS Board of Directors.

[2] For some years the present AMERICAN ROCKET SOCIETY was known as the American Interplanetary Society. For the sake of simplicity, only the ARS initials will be used.

was killed in a rocket automobile demonstration. Under these circumstances it was difficult to establish the conservatism of the rocket worker. But courageous people carried on. In 1931 G. Edward Pendray of the ARS, and his wife, went to Berlin, tried unsuccessfully en route to locate Esnault-Pelterie, and spent some time discussing rocket engine problems with Oberth, Winkler, and others. Later ARS rocket motors showed the influence of "Raketenflugplatz," the testing ground of the VfR. This visit was none too soon. The German Army confiscated both plans and personnel, by degrees, from Raketenflugplatz and set up another larger installation near Kummersdorf. By 1932 the hapless German society began to fade. With the start of Germany Army experimentation, international cooperation of an unexpected kind had given strong impetus to the art of rocketry. This cooperation was the ironclad, but ineffective, insistence by the Western Powers upon the provisions of the Versailles Treaty which, with catastrophic lack of foresight, had not included rockets on the list of weapons forbidden to the vanquished Germany.

In the later 1930's R. C. Truax followed Pendray to Europe, and the old-timers of the BIS still talk of the visit of the young midshipman of the United States Navy to demonstrate in London the rocket motor he had made with his Navy savings and on his leave.

Meanwhile, the ARS was growing. In 1930 the first bulletin of the Society appeared, containing an article on the "Universal Background of Interplanetary Flight." For many years this early ARS publication carried a column on "News from Abroad" suggesting strong interest in international astronautical affairs. France's great pioneer astronaut, Robert Esnault-Pelterie, presented to the Society an autographed copy of his historic "L'Astronautique," and on January 15, 1931, arrived in New York. Two thousand people turned out at an ARS meeting to hear him speak, although at the last minute illness detained him in his New York hotel and G. Edward Pendray had to read his speech.

The world was now in the throes of the great depression and rocketry was proceeding on a very small scale. In 1932 the Russian-Polish astronaut, A. Sternfeld, went to France where he saw A. Ananoff, leader in French astronautical circles. Ananoff, himself an ex-Russian, has for a long time attempted to maintain some sort of liaison with Russian astronautical scientists and has been responsible, through his books, for providing the West with knowledge of Russian writings.

In 1933 Philip Cleator founded the British Interplanetary Society which immediately became an influential force in astronautics. A year later he traveled to Germany to find that the VfR "was no more." He wrote that the Raketenflugplatz "appeared derelict." The Army had really taken over German rocketry.

The exigencies of warfare necessarily foreclosed cooperation between individuals in areas essential to national defense, and this situation has persisted from about 1934 to the present time. Within the framework of the establishments of friendly governments there has been very free exchange of information between individuals, and this undoubtedly has added immensely to the prospects of space flight. In addition to the wartime cooperation with the great scientists and engineers of our allies, we now have the significant benefit of the knowledge and experience of many of the great German experts. These include such men as von Braun, Dornberger, Ehricke, Klein, Koelle, F. Haber, H. Haber, Schaefer, Stuhlinger, Strughold, and even Hermann Oberth himself—to mention only a few.

Many of the major nations of the world now have rocket and astronautical societies belonging to the IAF, including Argentina, Spain, Italy, Great Britain, Denmark, Egypt, Germany, Japan, the Netherlands, Norway, Austria, Switzerland, Sweden, South Africa, Brazil, Yugoslavia, and the United States. In addition to the IAF member societies in those nations, societies have been formed recently in Mexico, Chile, Peru, and Canada. The journals and other publications of the societies are interchanged, membership is open to all qualified persons without regard to national barriers, correspondence is freely interchanged, and personal visits are becoming more and more frequent.

Since World War II many and singular missions have been accomplished by individuals in the cause of international cooperation in astronautics. The journeys of Cleaver and Ordway to Paris for the First Astronautical Congress; and of Durant, Elliott, Sawyer, and Haley to the Second Congress; the journeys of Durant through Scandinavia and northern Europe in the years thereafter; the "missionary" anabases of Sänger and Durant through Germany to Paris after Stuttgart, and of von Kármán and Haley from Paris to Zurich to Milan and from Brussels to Innsbruck during the Fourth and Fifth Congresses; the world forays of Singer and Alperin; the "proselyting" missions of Stehling to Canada and of Tabanera to Brazil, Chile, Peru, and Colombia; Haley to Mexico, France, and Cuba; the attendance at, preparation of, or delivery of papers at the several International Congresses by Romick, Gompertz, Ordway, Canney, Brannin, Gross, Klemperer, Petersen, Bergaust, Singer, Newell, Tousy, von Braun, Spitzer, Sawyer, Cornog, van der Wal, Schaefer, Ehricke, Rosen, Snodgrass, Stehling, Truax, Zaehringer, Stuhlinger, Strughold, Satin, Poland, Elliott, Pierce, Vaeth, Dornberger, Merrill, Rannie, Dryden, Alperin, and many others—just to mention those within the periphery of our special acquaintances—have contributed a composite impetus to international cooperation of immeasurable importance.

II

Around 1900 a wealthy society matron in Paris, a Madame Guzman, announced an award of 100,000 francs, the "Prix Guzman," to go to the first person to establish interplanetary communication. The optimism of the time is indicated by the stipulation that Mars, being too near at hand, would not be included in the competition. Needless to say, the prize was never claimed.

The first serious gesture in the direction of this form of international cooperation was the establishment in 1929 by Robert Esnault-Pelterie and a banker, Andre Hirsch, of the "REP-Hirsch Prize." This award consisted of the payment of 5000 francs to the author or experimenter who had done the most to further the idea of space travel in a given year, and was administered by the Société Astronomique de France. This prize was actually awarded between 1929 and 1936, with the exception of three years when it was considered that no worth-while contribution had been made. Hermann Oberth received a double award, 10,000 francs, in 1929 for his "Road to Space Travel." In 1930 and 1933 Pierre Montague received the prizes for papers on gaseous mixtures utilizable in the propulsion of rockets. In 1933, A. Sternfeld received an additional prize of 2000 francs for a paper, "Invitation to Cosmonautics." Louis Damblac received a "Prize of encouragement" of 2000 francs for a paper on proving ground tests. Alfred Africano and the AMERICAN ROCKET SOCIETY were honored in 1936 with the prize for design of a high altitude rocket.

The Hermann Oberth Medal was established after the war and is administered under the aegis of the IAF. In 1954 it was awarded to Strughold for his work in the field of space medicine. In a further postwar gesture of international recognition, Ananoff presented A. V. Cleaver of the BIS with a medal from the Aero-Club de France for his organizational work on the Second International Astronautical Congress in London, 1951.

At the Fourth International Astronautical Congress in Zurich the Gunter Loeser Memorial Medal was established, to be awarded annually on the basis of competition. The medal honors one of the founders of the IAF who was killed

when a helicopter, in which he was carrying out meteorological observations in Nebraska, crashed with the loss of all who were on board. The first such award is to be presented to the author of the best paper on "The Economics of Space Flight."

Germany's GfW has for some time kept an "Ehrenbuch der Astronautik," a roll of honor of astronautics, which now contains the names of Oberth, Ananoff, Esnault-Pelterie, von Pirquet, Pendray, and Cleaver, representing Germany, Austria, France, United States and Great Britain, respectively.

In 1952, through the efforts of Ananoff, and with the backing of the Groupement Astronautique Francais and the Aero-Club de France, a special astronautical medal was awarded posthumously to Ziolkovsky and was received by Russian officials of the Paris embassy. This medal was sent to Russia and placed on exhibit in Ziolkovsky's native town of Kaluga.

The American Rocket Society Astronautics Award was approved in 1954 by the ARS Board of Directors. It was proposed and endowed by A. G. Haley. The memorabilia consists of a bronze and gold leaf trophy designed by F. J. Malina and cast in Paris, and a bronze medal to be awarded annually, also designed by Malina, the die being made in Paris. Haley's endowment is for 101 years. T. von Kármán was awarded the medal in 1954. The award will be made without regard to nationality or society affiliation.

In other realms of international honors the BIS has made honorary members of von Braun, Esnault-Pelterie, Oberth, von Pirquet; the ARS has similarly honored Sir Hubert Wilkins, Fritz Zwicky, von Braun (honorary fellows); at the Zurich Congress the Swiss Society (S.A.A.) made honorary members of A. G. Haley and F. C. Durant, III.

III

International cooperation of a friendly competitive sort could be detected in the 1930's if one looked hard enough. Gerhard Zucker, owner of a mail-rocket franchise from the German Post Office, went to Scotland for a friendly mail-shooting contest between the two countries. A series of mishaps unfortunately cancelled the contest before a winner could be determined. Mail rockets were enjoying a vogue at the time, one which did not subside completely until some ten years later.

An international mail-shoot took place in 1936 at the Rio Grande between the two towns of McAllen, Texas, and Reynosa, Mexico. Several shots were fired each way and everyone enjoyed themselves. While the Americans and Mexicans exchanged rockets and pleasantries, plans were being drawn up in Germany for a vast rocket test installation at Peenemunde. One year later, Peenemunde was in operation.

In 1938 Captain Frank Whittle of the RAF successfully flew a turbojet-powered aircraft. As the turbojet, like the rocket, was a reaction engine, it created immediate interest in engineering circles. For the first time in history there was a prospect of an extremely fast reaction-powered aircraft. The political situation was getting tense in Europe. A civil war was in progress in Spain, and Hitler was expanding his control in Europe. America was showing signs of rearmament. By 1937 the French, under the initiative of Robert Lancement, felt that the time had arrived when it would be appropriate to make an astronautical exhibit—the place and occasion: Paris, during the 1937 International Exhibition. Lancement, writing of the astronautical exhibition that was placed in the Palais de la Decouverte, said he believed the word "astronautics" to be of French origin, with credit going to one J. H. Rosny. At the Paris exhibition material from America was shown, as well as from Austria, France, Germany, Great Britain, and Russia. The Cleveland Rocket Society sent a half-scale model of a research rocket.

In 1946 rockets again crossed the Rio Grande, but this time by accident: V-2 Number 14, fired from White Sands Proving Ground, went astray. The radio command to destroy did not register in the rocket and it crashed south of Juarez, producing a large crater. Friendly Mexican officials promptly telephoned the Commanding Officer at White Sands to give a full report.

IV

After years of private studies, and with the establishment of national rocket societies, it was only natural that the rocket technicians of the world should associate formally in an international organization. All who are interested in space travel realize that interplanetary flight will cost huge sums, and many, such as Germany's G. Loeser, hold that "this huge task cannot be performed by a single country." With genuine desire to affiliate the world's rocket scientists in an effective organization, the German GfW circulated a resolution for close international cooperation among the world's astronautical societies, and in June 1949 the GfW and the BIS formally proposed that an international congress on astronautics be held. A. Ananoff of France made elaborate preparations for the congress and he had the close cooperation of H. Gartmann of Germany and A. V. Cleaver of the BIS. The later contributions of Gartmann and Cleaver to the world organization were tremendous, but in fairness to Ananoff it must be recorded that he organized the Paris congress almost single-handedly.

The First International Astronautical Congress convened in Paris on September 30, 1950, with representatives of France, Germany, Austria, Great Britain, Denmark, Spain, and Argentina present. The United States did not participate. A. Ananoff was elected president of the Congress and H. Mineur was named honorary president. Madame Gabrielle Camille Flammarion and Madame de Vendeuvre were named vice presidents. Britain's Cleaver held the chair for the important October 2 session at which time the general nature of the federation was agreed upon. Eight resolutions were adopted, the substance of which was that an international organization should be formed for the study and development of interplanetary flight. The organization would be inaugurated at the next Congress. Before that time the various societies would send in proposals for a constitution, voting procedure, membership, and so on, which would be studied by the BIS and coordinated by it and by the temporary body headed by Sänger of Austria.

No technical sessions were held, but the delegates were received at the Palais de la Decouverte, where a visit to the Department Astronautique had been arranged. They were also guests at the atomic facility at Chatillon and at the Observatory of Meudon.

The First Congress was a significant step in the history of rocketry. Science had crossed national boundaries. Some of the most interested parties such as Oberth were prevented from attending because of visa trouble, but glowing reports of the Congress were brought back to them. The mission of the proposed new organization was clear: convert the rocket from an engine of war to a peaceful vehicle of interplanetary exploration.

During the winter of 1950 the national societies exchanged much correspondence. Drafts of organizational documents were reviewed. Two directors of the ARS became interested in the meeting and made plans to attend the next Congress.

The Second International Astronautical Congress was held in London at Caxton Hall, from September 3 to September 8, 1951. The original societies were represented, as was the United States, by the ARS, the Reaction Research Society, the Pacific Rocket Society, and the Detroit Rocket Society. Dutch and Canadian societies were then known to exist, but they did not participate in the Congress.

The Congress undertook to settle organizational problems. The name was established as the International Astronautical Federation. A secretariat was authorized in Switzerland. Sänger was elected president. Loeser of GfW and Haley of

At The Second IAF Congress, London, England, 1951

Front row, seated: Gunter Loeser, Hermann Oberth, Eugen Sänger, A. G. Haley.

Second row, standing: Josef Stemmer, Tomás Mur, E. V. Sawyer, T. Tabanera, L. J. Carter, F. Hecht, J. Jungklaass, H. H. Kölle, A. W. Hjerstrand, A. C. Clarke, F. C. Durant III, Eric Burgess, L. R. Shepherd.

At The Fourth IAF Congress, Zurich, Switzerland, 1953

Josef Stemmer, Eugen Sänger, L. R. Shepherd, and A. G. Haley.

ARS were elected vice presidents, and Stemmer of SAA was named secretary.

Final details as to the constitution were to be cleared up before the next Congress by vice presidents Loeser and Haley. The BIS had done much to prepare the tentative draft of the constitution, and during the Second Congress the all-important question of voting was studied. It had been recommended at the Paris Congress that each nation have one vote, and with the two German societies merged, it was feared that the United States would dominate voting with five votes. The Paris provision for one vote per nation was firmly established as the final voting arrangement.

Vice president Haley began the task of obtaining membership for the IAF in the International Council of Scientific Unions.

The Second Congress featured considerable technical exchange.[3] On September 8, 1951, a popular technical symposium was held wherein delegates discussed the over-all aspects of interplanetary flight. Some of the scientists proposed the foundation of an International Institute of Astronautics, but this move was postponed indefinitely. Astronautical displays were held in which the material used in the "Fifty Years of Flying" exhibition at Hendon earlier in 1951 were set up by the *London Daily Express*.

The primary scientific interest of the Second Congress was in the artificial satellite vehicle. The exchange of knowledge at London was the first organized attempt to promote world cooperation among rocket and astronautics workers. As such, it was a significant milestone in the history of science.

The Third International Astronautical Congress convened in Stuttgart on September 1, 1952. Sänger was re-elected president, and Haley was re-elected vice president. Shepherd of the BIS was elected vice president, and Stemmer was re-elected secretary.

The Constitution of the IAF which had been finally drafted during the previous year by the Loeser-Haley committee was adopted. The principle of one vote per nation, regardless of the size of the country or the number of its rocket or astronautical societies, which was strongly advocated by the ARS delegation at London, was approved. It was decided that the ARS would be the voting member from the United States.

The Congress then turned to technical matters. Prof. Oberth presented a paper which might well keynote all Congresses. He discussed "Private Research in Astronautics," in which he outlined the many problems which should be investigated with the aid of astronautical societies rather than large-scale, government subsidized classified research and which thereafter would form the basis of world cooperation. On this fundamental theme the Third Congress ended.

The Fourth International Astronautical Congress convened in Zurich in the Technical University on August 2, 1953. Societies from ten nations were represented and three new members were admitted: namely, the Philadelphia Astronautical Society, the South African Interplanetary Society, and the Jugoslavian Astronautical Society. Japan and Israel sent observers. The great shock was that France was not represented. New societies in Spain and Egypt were reported in formative stages.

Durant was elected president. Haley was elected vice president, Hecht was elected as second vice president, and Stemmer retained his position as secretary.

An important matter considered at the Fourth Congress was the establishment of an official publication. The need for such a publication is evident since members meet only once a year, and in some cases even the annual meeting cannot be attended by members located in distant lands. Recognizing the need for year-round means of international dissemination of information, the Congress appointed Hecht, Sänger, Casiraghi, Shepherd, and Ordway as a committee to set up a quarterly publication, *Astronautica Acta*.

The problem of obtaining recognition from World scientific organizations was given considerable attention and emphasis. Without such recognition the professional standing of the IAF is seriously impaired. Haley advised the delegates that the negotiations with the International Council of Scientific Unions were at a standstill because (1) an applicant for membership therein must be in *de jure* existence for six years, and (2) the General Secretary of the ICSU had expressed strong doubts that the IAF would be eligible for membership in any event.[4] Haley advised that the IAF should immediately serve as a consultative nongovernmental organization to UNESCO.

It was evident throughout the Fourth Congress that the IAF was becoming a potent factor in international efforts for scientific cooperation. Through the efforts of the Federation, for example, the United States Air Force gave permission for the Swiss Prof. Eugster to insert 400 gram packages of nuclear track plates in high-altitude constant-level balloons.

[3] The individual technical papers will not be discussed in this paper. They have been summarized in previous issues of JET PROPULSION: London Congress, Nov. 1951, vol. 21, no. 6, p. 192; Stuttgart Congress, Nov.–Dec. 1952, vol. 22, no. 6, p. 350; Zurich Congress, Nov.–Dec. 1953, vol. 23, no. 6, p. 384; Innsbruck Congress, Jan. 1955, vol. 25, no. 1, p. 46.

[4] A. V. Hill, General Secretary, ICSU, letter of January 21, 1953: "It is not for me to decide whether the International Astronautical Federation is qualified for membership of the International Council of Scientific Unions, but I have a strong impression the Executive Board will decide otherwise."

At The Fifth IAF Congress, Innsbruck, Austria, 1954

Seated at front table, clockwise: L. R. Shepherd, A. G. Haley, Hugh Dryden, Theodore von Kármán, Brigitta Legewie, and Richard F. Gompertz.

The Fifth International Astronautical Congress met at Innsbruck, Austria, starting August 2, 1954. The Austrian Society was host. The opening session was held in the Great Hall of the University of Innsbruck. Durant was re-elected President, and Tabanera of Argentina and Andersen of Denmark were elected vice presidents. (The ARS nominated Shepherd for President and Tabanera for vice president.) The ARS took a strong stand against continuation in office, contending, through Gompertz, its chief delegate, that offices should be rotated among delegates of all societies, large and small, otherwise a clique would dominate the Federation, resulting in ultimate disintgration. Prior to the meeting, members of the German and Swiss societies engaged in off-the-record electioneering aimed at the ARS nomination of Shepherd of BIS. Stemmer was re-elected secretary. The American Astronautical Society, the Spanish Astronautical Society, the Egyptian Astronautical Society, the Japanese Astronautical Society, and the Brazilian Interplanetary Society were admitted to membership. France sent a large delegation for the first time since 1952, but the Frenchmen did not seek formal accreditation. Russia again failed to send observers. The Croatian Society for Natural Sciences, Astronautical Section, sent an observer.

With increased membership and other encouraging signs of further international cooperation, the delegates approved publication of *Astronautica Acta* by Springer-Verlag, with editorial functions remaining with the IAF. The news section was dropped from *Astronautica Acta* and instead a special bulletin containing news was set up for publication by the Secretariat in Zurich.

An international astronautical research institute was again considered, but no action was taken. Research teams, abstracting activities, and the creation of IAF panels on such special subjects as nuclear propulsion, flight mechanics, history of astronautics, and the like were planned. A system of annual reports by these panels was proposed.

In the field of international affairs Haley reported that he had stopped in Paris en route to join von Kármán in Brussels and conferred with UNESCO officials, who promised to endeavor to divert Dr. Auger, Director of Natural Sciences of UNESCO, from a conference in Venice to observe the Innsbruck Conference. Haley reported that international acceptance of the IAF was maturing slowly but surely, and that the following year strong representations to UNESCO would be in order.

The developments concerning the earth satellite project just prior to the convening of the Sixth Congress at Copenhagen on August 1, 1955, deserve some background discussion.

The first report of the Space Flight Committee of the ARS issued in 1952 called for an orbital unmanned satellite project because "at this stage of man's knowledge the Committee believes that a study program of all phases of space flight, supported by the government, possibly by the National Science Foundation, would provide a sound basis for a vehicle construction program in the least possible time." We stated that the Committee "is of the view that exploratory space flight as a speculative venture into the unknown should be regarded as the ultimate objective of a reasonable effort on the part of the United States and mankind as a whole."

In 1953 the Chairman of the Space Flight Committee invited Alan T. Waterman, director of the NSF, to attend a plenary meeting of the Committee, and thereafter we issued a confidential report stating that the Space Flight Committee proposes that the "National Science Foundation study the utility of an unmanned satellite vehicle to science, commerce and industry, and national defense. Such a study should precede any considerations of feasibility and cost which could be undertaken if the utility study showed a definite need for a satellite vehicle."

We stated that an "example of these research uses might be: for a superior astronomical observatory site, for biological and chemical research utilizing nongravity conditions, for electronic research utilizing a more perfect vacuum of unlimited size for microwave research in free space, cosmic ray, and nuclear research, etc."

We certainly anticipated President Eisenhower at Geneva because we suggested the satellite be used for "large-scale accurate reference mapping and surveying" and "accurate mapping of areas not otherwise accessible to us." We pointed out that the foregoing is only a starting point and a first approximation, and that a further statement would be submitted to Dr. Waterman based upon "immense additional thinking."

In 1954 we submitted to the National Science Foundation a proposal "On the Utility of an Artificial Unmanned Earth Satellite." This report was written by Milton W. Rosen, who succeeded Haley as Chairman of the Space Flight Committee of the ARS. The report was backed up by a series of excellent studies on the utility of an artificial unmanned earth satellite. As late as the British Embassy party in Washington, June 9, 1955, honoring the Queen's birthday, we inquired of Dr. Waterman as to whether any decisions had been reached, and he replied that our report was under study.

Two months earlier, in April 1955, the Russians had announced the organization, under the directorship of Kapitsa, of "The Interdepartmental Commission for Interplanetary Communications."

In any event, developments were in the air, so we proceeded to Paris to organize finally the UNESCO association and to help organize a French astronautics society.

Only hours before the satellite announcement from the White House we conferred with V. Hercik, who is in charge of international organizations for UNESCO, and with N. Β. Cacciapuoti, associate director of the Department of Natural Sciences of UNESCO.

We were advised that the UNESCO program committee will meet in 1956 at New Delhi. On this occasion the program for 1957 and 1958 will be established. Both officials showed extreme interest in the purposes of the IAF, as set forth in the Constitution of the IAF. They both said that UNESCO would be most happy to have a well thought-out space flight program presented to it, and that such a program might even be expedited on an emergency basis. They concluded that with such a program authorized, the IAF could then qualify as a consultative nongovernmental adjunct of UNESCO.

(Later, in Copenhagen, at the plenary session of the Sixth Congress, we reported on this mission, and a Committee on International Affairs was again constituted: Haley (ARS), chairman; and Shepherd (BIS), Sänger (GfW), Hjerstrand

(SJS), and Tabanera (SAI). The Committee met and decided to submit recommendations to UNESCO within three months.)

After our UNESCO conference in Paris, we had a luncheon meeting with General Bergeron, Chairman of the Committee for Scientific Research for the National Defense; Chief Engineer Wanner of the Aeronautical Technical and Industrial Department of the Defense Ministry; Professor Vassy of the National Meteorological Department; Delval, Technical Director of SNCASO; Pillorget, Director of the Technical Association for the Study of Rocketry; Turcq, President of the Turcq Corporation; Corbeau, Principal Engineer of the Armament Section for Research and Development of the Defense Ministry; Moureau, Director of the Municipal Laboratory; Wattendorf, Director of the AGARD Secretariat; Malina, former Director of JPL; F. S. Singer of the University of Maryland, and Haley, host of the meeting. The meeting was arranged through the good offices of Dr. Wattendorf.

At this conference General Bergeron gave assurances that a French astronautical society would be formed and that its membership would consist of the most capable scientists, engineers, and industrialists of France. He said that the organizational procedures should be completed by October 1955. We discussed minimal orbital satellites proposed by Singer and others, and we touched upon many other peaceful applications of rocket power to space vehicles.

Thus, on Friday morning (Paris time), July 29, 1955, officials of UNESCO signified their agreement to cooperate with the IAF and its space flight program. In the afternoon a group of the leading French scientists and engineers agreed to join in the enterprise of peaceful astronautics—to organize a society for this purpose and to join the IAF. And in the evening the White House announcement of the satellite project was released from Washington. The further significance is that the Space Flight Committee of the ARS had anticipated the details and even much of the language of the American announcement. There were some changes—the MOUSE became the BIRD, and so on. But the substance of the First, Second, and Third Reports of the Space Flight Committee in many respects paralleled the official announcement, and it was most gratifying that a great government proposed to go forward with a minimal satellite in connection with the program of the International Geophysical Year.

Upon the advice of Professor Hecht, the Editorial and Advisory Boards of the *Astronautica Acta* were strengthened by the addition of new members. The Constitution was amended to permit the adherence of Corresponding Members—educational and other institutions, which could not qualify as "Societies"—but careful limitations were placed upon such adherence, the main safeguard being that any institution applying from a particular nation must have the approval of the Voting Member Society of such nation.

All the officers were reelected, and Darrell H. Romick, as Acting Chief Delegate of the ARS, again nominated Shepherd of BIS and again expressed the view of the ARS that the officers should rotate and that continuation in office is undesirable.[5]

Of particular interest at this Congress was the attendance in person of a two-man delegation from the Yugoslavia Society—Ajvaz and Sivcev. These engineers attended the meetings faithfully. During the course of the second day of the plenary session, Ogorodnikov and Sedov, Russian academicians, also appeared and attended the business and technical sessions of the Congress. The Russians necessarily attended as observers because no rocket society from Russia had applied for membership. It appears that application for membership will be made in the near future through the Academy of Science, Moscow.

It was decided that the next Congress will be held in Rome during the second week in September. This will give many interested persons an opportunity to first attend the Farnborough Aeronautical Exhibition in England and then attend the IAF Congress.

V

Achieving international cooperation in the fields of rocketry and astronautics through official channels and governmental organizations is really the ultimate objective of our efforts as long as the race of man adheres to the principle that it is desirable to have government under law, and as long as the real objective is the peaceful conquest of the universe and the addition of the universe to our living space. The true achievement of the announcements of July 29, 1955 (Washington, D. C.) and of April 15, 1955 (Moscow) is that neither announcement engendered threats of war. If such announcements had indicated that there was any thought of the invasion of the sovereignty in any aspect of one or the other of the areas of influence of the great powers by the use of a satellite, an act of war would have been posted.

On the national level, cooperation may be achieved by legislation and through diplomatic negotiations and pronouncements. Representative Karsten introduced a Bill in the House of Representatives on August 2, 1955 [H.R. 7843] to create a Joint Committee on Extraterrestrial Exploration. This Committee would consider all legislative proposals with respect to space travel. On the same level, examples of diplomatic action are the White House announcement of July 29, 1955, and the concurrent announcements of the National Science Foundation and the National Academy of Sciences, as well as the Moscow announcement of April 15, 1955, of the creation of the Russian Commission for Interplanetary Communication.

On the international level, we have the United Nations and its subsidiary organizations. No one is wise enough to describe the course of the eventual evolution of space government, but, for the moment at least, the most eligible agency would appear to be the United Nations and its subsidiary affiliates. Basic investigations in the realm of the natural sciences would logically fall under the jurisdiction of UNESCO. The tremendous demand for radio spectrum in connection with the exploration of space and the colonization of other planets would certainly require the International Telecommunications Union to make adequate provisions therefor.

It is safe to assume that even as the Congress of the United States has already been presented with a proposition with respect to regulating extraterrestrial exploration, the United Nations and its agencies will be asked to consider in detail the myriad problems that this greatest of all materialistic events in the history of man now present.

[5] At the Zurich Congress the then President simply announced the names of the new officers. At the Innsbruck and Copenhagen Congresses the Swiss delegates jumped to their feet to make the first nominations—a most unseemly display on the part of the Society of the Secretariat. It would appear that the Swiss desire not only to maintain the Secretariat, but also to control the election of the other officers. It is hoped these examples of petty politics will not recur. The fact that officers so chosen may be competent has nothing to do with the principles involved.

Twenty-Five Years of Rocket Development

(*Continued from page 603*)

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34 "Mathematical Theory of Rocket Flight," by J. B. Rosser, R. R. Newton, and G. L. Gross, McGraw-Hill Book Co., New York, 1947.

35 "Steady Flow with Mass Addition in Solid Rockets," by E. W. Price, *Journal of the American Rocket Society*, vol. 23, no. 4, July-Aug. 1953, p. 237.

36 "A Correlation of Interior Ballistic Data for Solid Propellants," by R. D. Geckler and D. F. Sprenger, JET PROPULSION, vol. 24, no. 1, Jan.-Feb. 1954, p. 22.

37 "Erosive Burning of Some Composite Solid Propellants," by L. Green, Jr., JET PROPULSION, vol. 24, no. 1, Jan.-Feb. 1954, p. 9.

38 "Unstable Burning of Solid Propellants," by L. Green, Jr., JET PROPULSION, vol. 24, no. 4, July-Aug. 1954, p. 252.

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42 "Problems in the Application of Nuclear Energy to Rocket Propulsion," H. S. Seifert and M. M. Mills, *JPL Memo* 3–4, Jan. 23, 1947.

43 "Nuclear Reactors for Rockets," by J. McCarthey, JET PROPULSION, vol. 24, no. 1, Jan.-Feb. 1954, p. 36.

44 "Problem of Cooling Nuclear Working Fluid Rockets Operating at Extreme Temperature," by H. J. Kaeppeler, JET PROPULSION, vol. 24, no. 5, Sept.-Oct. 1954, p. 316.

45 "Nuclear Energy and Rocket Propulsion," by A. V. Cleaver, *The Aeroplane*, June 5, 1955, pp. 736–738.

46 "Injector Spray and Hydraulic Factors in Rocket Motor Analysis," by K. R. Stehling, *Journal of the American Rocket Society*, vol. 22, no. 3, May-June 1952, p. 132.

47 "Rocket Engine Design Philosophy," by Robert Gordon, American Rocket Society Preprint no. 144-54 (1954).

48 "Fluctuations in a Spray Formed by Two Impinging Jets," by M. F. Heidmann and J. C. Humphrey, *Journal of the American Rocket Society*, vol. 22, May-June 1952, p. 127.

49 "The Liquid-Phase Mixing of a Pair of Impinging Streams," by J. H. Rupe, *JPL Progress Rep.* 20-195, Aug. 6, 1953 (see p. 33).

50 "The Ignition of Fuel Droplets Descending Through an Oxidizing Atmosphere," by H. L. Wood and D. A. Charvonia, JET PROPULSION, vol. 24, no. 3, May-June 1954, p. 162.

51 "Stream Paths from Rotating Liquid Injectors," by H. S. Seifert, E. P. Baxter, and J. M. Schmidt, *JPL Memo* 4-42, Sept. 1948.

52A "Materials for Combustion Chambers," by H. G. Mebus, *Interavia*, vol. 8, no. 5, May 1953, pp. 266–267.

52B "Strength of Heated Steels," by R. L. Noland, *Journal of the American Rocket Society*, vol. 21, no. 6, Nov. 1951, p. 154.

53. "Report on Motor Tests," by J. Shesta, *Astronautics*, no. 49, August 1941, p. 3 (shows 1st fuel-cooled motor by J. Wyld).

54 "The Mechanics of Film Cooling—Part I," by Eldon Knuth, JET PROPULSION, vol. 24, no. 6, Nov.-Dec. 1954, p. 359.

55 "Transpiration Cooling in Porous Metal Walls," by E. Mayer and J. G. Bartas, JET PROPULSION, vol. 24, no. 6, Nov.-Dec. 1954, p. 366.

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57 "Some Experiments on Flow Separation in Rocket Nozzles," by K. Scheller and J. A. Bierlein, *Journal of the American Rocket Society*, vol. 23, no. 1, Jan.-Feb. 1953, p. 28. (See also L. Green, p. 34.)

58 "Stability and Control of Liquid Propellant Rocket Systems," by Y. C. Lee, M. R. Gore, and C. C. Ross, *Journal of the American Rocket Society*, vol. 23, no. 2, March-April 1953, p. 75.

59 "Importance of Mixture Ratio Control for Large Rocket Vehicles," by R. H. Reichel, JET PROPULSION, vol. 25, no. 6, June 1955, p. 291.

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66 "Principles of Jet Propulsion," by M. J. Zucrow, John Wiley & Sons, Inc., New York, 1948, 563 pp.

67 "Liquid Propellant Rocket Motors," by B. R. Diplock, D. I. Lofts, and R. A. Gumston, *Journal of Royal Aero. Soc.*, vol. 57, Jan. 1953, pp. 19–28 incl.

68 "The Use of Weapon Systems Engineering Concepts in the Design of Solid Propellant Rocket Power Plants," by H. L. Thackwell, ARS Pap. no. 232–55.

Tentative Schedule of Meetings in Which ARS Will Participate During 1956

Date	Meeting	Place	ARS Sessions and Tentative Themes	Technical Events Chairman	Abstracts due
Jan. 23–26	IAS Annual	Hotel Astor, New York	2 sessions—rocket propulsion	D. F. Ferris, Reaction Motors, Inc., Rockaway, N. J.	Aug. 1, 1955
Mar. 14–16	ASME Aviation Conference	Hotel Statler, Los Angeles	3 sessions—high temperature, rocket engines, instrumentation	David Shonerd, Aerophysics Development Corp., Box 949, Santa Monica, Calif.	Nov. 30, 1955
May 23–25	ASME-Engineering Inst. of Canada Joint Meeting	Mount Royal Hotel, Montreal	1 session—guided missiles	.....	Jan. 1, 1956
June 17–21	ARS-ASME Semi-Annual Meeting	Hotel Statler, Cleveland	4 sessions—liquid rockets, solid rockets, ramjets, satellites	Henry C. Burlage Case Inst. of Tech., 10900 Euclid Ave., Cleveland 6, Ohio	Jan. 15, 1956
Sept.	Seventh IAF Congress	Rome	Astronautics	.....	Feb. 15, 1956
Sept.	ARS Fall Meeting	Buffalo	4 to 6 sessions—propellants, combustion, telemetering	.....	Feb. 15, 1956
Nov. 25–30	ARS-ASME Annual Meeting	Hotel McAlpin, New York	12 to 14 sessions	.....	May 15, 1956

Presentation of the Proposed American Standard Letter Symbols for Rocket Propulsion

ROBERTSON YOUNGQUIST[1] and J. P. LAYTON[2]

WITH this article, the rocket propulsion industry and profession are invited to comment upon and to criticize the present informal (and therefore unofficial) publication of a proposed American Standard Letter Symbols for Rocket Propulsion. In responding to this invitation, it will be appreciated if all comments are addressed to J. P. Layton, Secretary, ASA Y10 Subcommittee 17, c/o The American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N. Y., prior to December 15, 1955. Alternatively, for those who will be attending the 25th Anniversary Annual Meeting of the American Rocket Society in Chicago this month, a cordial invitation is extended to participate in the Forum on Letter Symbols for Rocket Propulsion at 4 p.m. on Tuesday, November 15, 1955.

BACKGROUND. Preparation of the proposed standard has been the responsibility of Subcommittee No. 17 on Rocket Propulsion, one of seventeen subcommittees appointed by Sectional Committee ASA Y10 on Letter Symbols. The other subcommittees cover Mathematics, Hydraulics, Mechanics of Solid Bodies, Structural Analysis, Heat and Thermodynamics, Photometry, Electrical and Magnetic Quantities, Radio, Physics, Chemical Engineering, Acoustics, Meteorology, Feedback Control Systems, Abbreviations, and General Principles of Letter Symbol Standardization.

Sectional Committee Y10 was organized under the procedure of the American Standards Association in January 1926 with the American Society of Civil Engineers, the American Institute of Electrical Engineers, the American Society for Engineering Education, The American Society of Mechanical Engineers, and the American Association for the Advancement of Science, as joint sponsors. The committee was reorganized in October 1935, and it now consists of representatives of 42 national societies and associations, under the reorganization of April 1951. The American Society of Mechanical Engineers has assumed the role of sole sponsor and maintains a Standards Department devoted to the editing and publishing of American Standards.

Subcommittee No. 17 was established as a result of discussions arising during 1952 on the revision of American Standard, Letter Symbols for Aeronautical Sciences, ASA Z10.7—1950. During its discussions, Subcommittee No. 7 on Aeronautical Sciences found that a great many specialized terms in the field of rocket propulsion (particularly concerning internal aspects of rocket powerplants) were being proposed for inclusion in the revised Aeronautical Sciences Standard. C. W. Chillson, a member of Subcommittee No. 7, undertook the task of recommending which of these symbols should be included in the revised Aeronautical Sciences Standard. Subcommittee No. 7 adopted several of the proposed symbols and at the same time recommended to the ASA Sectional Committee on Letter Symbols the establishment of a new subcommittee to formulate an American Standard on Letter Symbols for Rocket Propulsion.

Subcommittee No. 17 was originally constituted in 1952 and held the first of its eight formal meetings to date on June 2, 1953, in Los Angeles, California. At this and subsequent meetings, policies were established as described below.

POLICIES. The two fundamental policies of the American Standards Association are (1) that all interested parties shall be given opportunity to comment on a proposed standard and (2) that the adopted standard shall be a consensus. In addition to following these and the General Principles of Letter Symbol Standardization which are set forth in a later portion of this article, the subcommittee established the following items of policy as the need arose:

1 Scope. The proposed Standard should be confined to liquid and solid propellant rocket propulsion and should deal with the rocket propulsion system and rocket propulsion as it relates to the application. Consideration of symbols for specialized systems shall be deferred.

2 Symbol with Subscript. Where the symbol with its subscript is unique to the concept, then the symbol with the subscript will be listed. In all other cases the symbol will be listed alone and a separate list of general subscripts will be established. The preferred order of subscripts is to list first substance and then station, when both are used. Subscripts should be standardized only where essential.

3 Current Symbols Versus Improved Symbols. Letter symbols already adopted in other American Standards and symbols generally used in the rocket literature should be retained wherever practicable. Give preference generally to the symbol of widest usage among several possible symbols. In specific cases where an improved symbol is indicated, it should resemble the symbol currently used in rocket propulsion. Improvement consists of, in order of importance: (a) a symbol or concept consistent with usage in other fields as set forth in existing standards, (b) a technically more accurate concept, and (c) a simpler symbol.

4 Fundamental Versus Hardware Terminology. Principal symbols are to be assigned to basic concepts only; relation to a physical geometry or parts should be by subscript.

5 Specific Definition of Concepts. A basic concept may have variations in definition. Therefore, only one primary symbol (or its alternates) should be identified with any one basic concept. Variations in definition of a concept may arise from (a) arbitrarily selected values used in the definition, or (b) differences in terminology describing the concept. These variations should be resolved by use of appropriate subscripts.

6 Upper Case Versus Lower Case. For primary symbols use lower case letters for unit qualities and upper case letters for total quantities to the extent consistent with conventional employment in related fields and standards. For subscripts, lower case usage is preferred (upper case should be employed only to avoid confusion or in established symbols). Stations should be denoted by consecutive numerical subscripts.

7 Organization of Standard. The preliminary form of the Proposed Standard will be similar to that of Letter Symbols for Aeronautical Sciences.

8 Alternate Listing of Symbols. When there is more than one symbol or more than one term for a given subject or

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[2] Secretary, ASA Y10 Subcommittee No. 17.

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quantity, the Standard should list only the more important alternates and should also express a definite preference for one of the several symbols or terms.

9 Total Versus Static Quantities. (Discussed below.)

10 Duration and Time Terms: Because many duration terms are both complex and are defined in various specifications, detailed symbols for these terms should not be included in the Proposed Standard.

11 Inclusion of General Terms. All symbols in frequent use in rocket propulsion, although included in other Standards, should appear in the Proposed Standard to the extent adjudged appropriate by the subcommittee.

12 Adoption of System of Units. Symbols will be placed in dimensions of mass, length, time, and temperature (M, L, T, and θ) as an aid in defining the concept, although these do not constitute a part of the Proposed Standard.

13 Symbols for Simple Ratios. For the simple ratio of two variables with assigned symbols (without subscripts), no special symbol should be used except where prescribed by long usage.

14 Mass, Weight, and Gravity Symbols. (Discussed below.)

PRINCIPAL QUESTIONS. No attempt can be made here to present the subcommittee's detailed reasoning on its action on each of the two-hundred-odd proposed symbols. However, with a view to soliciting professional comment, the subcommittee is anxious to present herewith a brief review of some of the principal questions encountered and the actions taken.

One principal question which arose was that of distinguishing between total and static quantities. One school prefers the use of upper and lower case letters, respectively. The other prefers the use of uniform case with distinguishing subscripts. The subcommittee concluded that the latter usage should be adopted.

Another principal question concerned the proper treatment of the concepts and terminology involving mass, weight, and gravity. The subcommittee, after long consideration, came to the following conclusion: "The field of rocket propulsion deals with quantities of matter at drastically changing and changeable locations. In ordinary engineering practice, gravity variation is not an important consideration, and it has become common practice to use mass and weight quantities interchangeably. Because weight force changes with the gravitational field, this engineering practice is becoming increasingly unacceptable in the rocket propulsion field. Adoption of mass units aids the rocket engineer in always keeping clear the distinction between the basic concepts of mass and force as expressed in Newton's equation $F = \frac{d(mv)}{dt}$. This subcommittee has attempted to define a nomenclature which is correct and also acceptable to the majority of the people in the field. Gravitational quantities and concepts of mass and weight have been carefully defined. In view of the widespread confusion of these terms, it is suggested that their relationships be reviewed by all users of the proposed standard." For example, use of the concept *specific impulse*, a concept based on "weight flow" rate, can lead to uncertainties when a variable gravitational field is considered. The concept nevertheless has been retained because of its widespread usage. However, the subcommittee recommends that emphasis be put on use of the older and more fundamental concept of *effective exhaust velocity* (thrust per unit mass flow, or impulse per unit quantity of matter), in place of *specific impulse*, for future analyses.

A third question concerned the adoption of the symbol $\dot{m}$ (em-dot) for mass flow per unit time as against m or w. It was the feeling of the subcommittee that, despite the conflict with some existing standards and the general undesirability of including a mathematical operator as part of a symbol, the unequivocal meaning of $\dot{m}$ as the first derivative of mass with respect to time warranted the adoption of this symbol for the concept of mass flow, which is so important in the rocket propulsion field.

The question of the symbol for *specific impulse* was also considered at length. The symbol I_s was finally selected because of a desire to simplify the symbol and avoid double-letter subscripts. Alternate symbols did not appear attractive based on an extensive survey of technical personnel from which no overwhelming preference was indicated.

In considering these and many other questions, the members of the subcommittee sought to arrive at decisions best satisfying the sometimes conflicting requirements for good symbols. Conference-type discussions resulted in substantial agreement in all cases. The subcommittee, whose personnel is listed below, regards the Proposed Standard as practicable. Written comment on the subject is solicited.

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Proposed

American Standard

Letter Symbols for Rocket Propulsion

General Principles of Letter Symbol Standardization

1 Letter Symbols. A letter symbol for a physical quantity is a single letter, specified as to general form of type. It is available for use within a mathematical expression. This primary symbol may be modified by subscript or superscript. In a published work, the same primary letter symbol should appear throughout for the same generic physical quantity, regardless of the units employed, and of special values assigned.

Usually, one may readily distinguish between letter symbols for physical quantities, and other published symbols and signs. The latter, while more or less analogous, belong largely to topics not treated here, such as (i) mathematical signs, (ii) chemical symbols, (iii) punctuation, (iv) proofreading signs, and (v) abbreviations (widely used in tabulations).

2 Four General Requirements for Published Symbols and Signs. As is generally recognized, each published symbol or sign, of whatever kind, should be at least:

(*a*) *Standard, where possible.* In the use of published symbols, authors of technical works (including textbooks) are urged to adopt the symbols in this and other current standard lists, and to conform to the principles stated here. An author should give a table of the symbols he uses and their respective interpretations, or else refer to a standard list as source for symbols which he is using but does not explain. For work in a specialized or developing field, the author may need symbols in addition to those already contained in standard lists. In such a case he should be careful to select simple suggestive symbols which yet avoid conflict in the given field and in other closely related special fields. Except in this situation, he should not introduce new symbols or depart from currently accepted notation.

(*b*) *Clear in reference.* One should not assign to a given symbol different meanings in such a manner as to make its interpretation in a given context ambiguous. Conflicts must be avoided. Often a listed alternative symbol or a modifying subscript is available and should be adopted. Except in brief reports, any symbol not familiar to the reading public should have its meaning defined in the text. The units should be indicated whenever necessary.

(*c*) *Easily identified.* Because of the many numerals, letters and signs which are similar in appearance, a writer should be careful in calling for separate symbols which in published form might be confused by the reader. For example, many letters in the Greek alphabets (lower case and capital) are practically indistinguishable from English letters; the zero is easily mistaken for a capital O.

(*d*) *Economical in publication.* One should try to keep at a minimum the cost of publishing symbols. In particular: (i) Notations which call for handsetting of movable type should be rejected in favor of forms adapted to modern mechanical methods of composition. (ii) No one work should use a great variety of types and special characters. (iii) Handwriting of inserted symbols, in copy largely typewritten and to be reproduced in facsimile, should not be excessive. (iv) Often a complicated expression appears as component part of a complex mathematical formula; for example, as an exponent of a given base. Instead, one may introduce, locally, a single letter to stand for such a complicated component. An explanatory definition should then appear in the immediate context.

3 Secondary Symbols. Subscripts and superscripts are widely used and for a variety of conventional purposes. For example, a subscript may indicate: (i) the place of a term in a sequence or matrix, (ii) a designated state, point, part, or time, or system of units, (iii) the constancy of one independent physical quantity among others on which a given quantity depends for its value, (iv) a variable with respect to which the given quantity is a derivative. Likewise, for example, a superscript may indicate: (i) the exponent for a power, (ii) a distinguishing label, (iii) a unit, or (iv) a tensor index. The intended sense must be clear in each case. Several subscripts or superscripts sometimes separated by commas may be attached to a single letter. A symbol with a superscript such as a prime (′) or second (″), or a tensor index, should be enclosed in parentheses, braces, or brackets before an exponent is attached. So far as logical clarity permits, one should avoid attaching subscripts and superscripts to subscripts and superscripts. Abbreviations, themselves standardized, may appear among subscripts. A conventional sign, or abbreviation, indicating the adopted unit may be attached to a letter symbol, or corresponding numeral. Reference marks, such as numbers in distinctive type, may be attached to words and abbreviations, but not to letter symbols.

4 Typography. Letter symbols for physical quantities, and their subscripts and superscripts, whether upper case, lower case, or in small capitals, when appearing as light-face letters of the English alphabet, are printed in italic (sloping) type. Arabic numerals, and letters of other alphabets used in mathematical expressions are normally printed in vertical type. When a special alphabet is required, boldface type is to be preferred to German, Gothic or, Script type. In material to be reproduced in facsimile, from copy largely typewritten, letters which would be boldface in print, may be indicated to be such by special underscoring, while the few distinct letters used from other alphabets, if carefully made, should be self-explanatory. It is important to select a type face which has italic forms, and with clearly distinguished upper case, lower case, and small capitals. Only type faces with serifs are recommended.

Letter Symbols for Rocket Propulsion

A symbol designated as an alternate is not preferred. Symbols having equal rank are not designated as alternates. The dimensions given in the third column and the definitions given in the fifth column are merely illustrative and form no part of the present standard. With regard to the indicated dimensions, and in a particular system of units, M represents Mass, L represents Length, T represents Time, and θ represents Temperature.

Letter Symbols for Principal Concepts

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
a	acceleration, linear	LT^{-2}	Z10.2, Z10.4, Y10.10, Z10.12	—
a	acoustic velocity; speed of sound	LT^{-1}	Y10.7, Y10.10	—
a	burning-rate constant	See Remarks	—	$a = \frac{r}{(p_c)^n}$
a	work content per unit mass (or per unit weight); specific work content	L^2T^{-2} (L)	Z10.4, Z10.6	—
A	area, cross-sectional	L^2	Z10.2, Z10.4, Z10.6, Y10.7, Z10.8, Y10.9, Z10.12	—
A	work content, in general or per mole	ML^2T^{-2}	Z10.4	$A = U - TS$
b	breadth, width	L	Z10.2, Z10.4, Z10.12	—
c	velocity, effective exhaust	LT^{-1}	—	$c = \frac{F}{\dot{m}} = \frac{F}{\dot{w}}\left(\frac{g}{g_c}\right) = I_s\left(\frac{g_0}{g_c}\right) = C_F c^*$
c	velocity of light	LT^{-1}	Z10.9, Z10.6, Y10.9	—
c_p	specific heat capacity at constant pressure	$L^2T^{-2}\theta^{-1}$	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
c_v	specific heat capacity at constant volume	$L^2T^{-2}\theta^{-1}$	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
c^*	velocity, characteristic	LT^{-1}	—	called "see-star" $c^* = \frac{A_t p_c}{\dot{m}} = \frac{A_t p_c}{\dot{w}}\left(\frac{g}{g_c}\right)$
C	coefficient	—	Z10.2, Y10.7, Z10.12	—
C_d	discharge coefficient	—	—	$C_d = \frac{Q}{A\sqrt{2gh}}$
C_D	drag coefficient	—	—	—
C_D	mass flow factor	TL^{-1}	—	$C_D = \frac{\dot{m}}{p_c A_t} = \frac{\dot{w}}{p_c A_t}\left(\frac{g_c}{g}\right) = \frac{1}{c^*}$
C_F	nozzle thrust coefficient	—	—	$C_F = \frac{F}{p_c A_t}$
d	diameter	L	Z10.3, Z10.4, Y10.7, Y10.9	—
D	diameter	L	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10, Z10.12	—
D	drag	MLT^{-2}	Y10.7	—
e	energy, per unit mass (or per unit weight); specific energy	L^2T^{-2} (L)	—	—
E	energy, in general or per mole	ML^2T^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.10, Z10.12	—

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
E	modulus of elasticity; Young's modulus	$ML^{-1}T^{-2}$	Z10.3, Z10.6, Y10.7, Z10.8, Y10.9	—
f	coefficient of friction; friction factor	—	Z10.2, Z10.6, Z10.12	—
f	frequency	T^{-1}	Z10.3, Z10.6, Y10.7, Z10.8, Y10.9	—
F	force; thrust	MLT^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	—
g	free energy, per unit mass (or per unit weight); specific free energy	L^2T^{-2} (L)	Z10.4, Z10.6	—
g	gravitational acceleration, general	LT^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Y10.12	used where it is not necessary t distinguish between the loc and the standard value whic is given below; with appropri ate subscript this symbol de notes local gravitational accele ation at a given location
g_c	gravitational conversion factor	—	Z10.4, Z10.12	proportionality constant in th general relation: force = quantity of matter × accele ation ÷ g_c; g_c is numerically equal to g_0 when units ar pound-matter and standar pound-force, and g_c is unit when units are such that for = quantity of matter × accele ation
g_0	gravitational acceleration, standard	LT^{-2}	Z10.4, Z10.6, Z10.12	internationally adopted v value of 980.665 cm sec^{-2} o 32.1740 ft sec^{-2}
G	free energy, in general or per mole	ML^2T^{-2} (L^2T^{-2})	Z10.4, Z10.6, Z10.12	$G = H - TS$
G	ratio of solid propellant surface area ahead of a given plane to the port area of that plane	—	—	—
G	mass velocity	$ML^{-2}T^{-1}$	Z10.12	$G = \frac{\dot{m}}{A} = \frac{\dot{w}}{A}\left(\frac{g_c}{g}\right)$
h	altitude	L	Z10.6, Y10.7, Z10.8, Y10.10	—
h	height; depth	L	Z10.4, Z10.6	—
h	enthalpy, per unit mass (or per unit weight); specific enthalpy	L^2T^{-2}	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
h	head	L	Z10.6	preferred; H is alternate.
h	heat flow rate per unit of area per degree across a boundary surface; film coefficient of heat transfer	$MT^{-3}\theta^{-1}$	Z10.4, Y10.7, Z10.12	h is an average property of a par ticular boundary condition
h	Planck constant	ML^2T^{-1}	Z10.4, Z10.6, Y10.9	—
H	enthalpy, in general or per mole	ML^2T^{-2}	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	$H = U + \frac{pV}{J}$
H	head	L	Z10.2	alternate; h is preferred

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
I	moment of inertia, mass	ML^2	Z10.3, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10, Z10.12	—
I	impulse; total impulse	MLT^{-1}	Y10.7, Y10.10	preferred; I_t is alternate
I_s	specific impulse	LT^{-1}	—	preferred concept; specific thrust is alternate $I_s = \frac{F}{\dot{w}}\left(\frac{g}{g_0}\right) = \left(\frac{g}{g_0}\right)\frac{\int F\,dt}{W}$ commonly written as $I_s = \frac{F}{\dot{w}}$ with dimension of T
I_t	total impulse; impulse	MLT^{-1}	—	alternate; I is preferred
J	mechanical equivalent of heat	—	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
J	radiant energy per unit of time for any area A per unit of solid angle in the direction θ; radiant intensity for a body	MT^{-3}	Z10.4, Z10.6, Y10.9, Y10.10	the radiant intensity from a source J_s is sometimes called steradiance. $J = \int N \cos\theta\, dA$
J	ratio of nozzle throat area to port area	—	—	$J = \frac{A_t}{A_p}$
k	erosion constant in the linear velocity burning rate law	$L^{-1}T$	—	$\frac{r}{r_0} = 1 + ku$
k	specific heat ratio	—	Z10.4, Y10.7, Z10.12	alternate; γ is preferred $k = c_p/c_v$
k	thermal conductivity	$MLT^{-3}\theta^{-1}$	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	—
K	bulk modulus of elasticity	$ML^{-1}T^{-2}$	—	—
K	ratio of burning surface to throat area	—	—	—
K_c	equilibrium constant in chemical reaction in terms of concentrations	—	—	—
K_p	equilibrium constant in chemical reaction in terms of partial pressures	—	—	—
l	length; distance	L	Z10.3, Z10.4, Z10.6, Y10.7, Y10.9	—
L	lift	MLT^{-2}	Y10.7	—
L	length	L	Z10.2, Z10.4, Z10.12	—
L^*	characteristic length of combustion chamber	L	—	called "ell-star" $L^* = V_c/A_t$
m	fundamental measure of a quantity of matter; mass	M	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	$m = w\left(\frac{g_c}{g}\right)$
$\dot{m}$	mass flow per unit time	MT^{-1}	—	$\dot{m} = \dot{w}\left(\frac{g_c}{g}\right)$
M	Mach number	—	Y10.7	$M = \frac{V}{a}$
M	molecular weight	—	Z10.4, Z10.6, Z10.12	—

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
M	moment	ML^2T^{-2}	Z10.3, Y10.7, Z10.8	—
n	exponent of polytropic expansion	—	Z10.4, Y10.10	$pv^n = \text{const}$
n	burning rate exponent	—	—	$r = a(p_c)^n$
n	revolutions per unit time; rotational speed	T^{-1}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.12	preferred; N is alternate
N	number, in general	—	Z10.2, Z10.3, Z10.4, Y10.7, Y10.10, Z10.12	—
N	revolutions per unit time; rotational speed	T^{-1}	—	alternate; n is preferred
N_s	pump specific speed	$L^{3/4}T^{-3/2}$	—	$N_s = \frac{n\sqrt{Q}}{(h_e - h_i)^{3/4}}$ used only when n—rpm Q—gpm $(h_e - h_i)$—head rise across pump in feet
Nu	Nusselt number	—	—	$Nu = \frac{hL}{k}$
p	pressure	$ML^{-1}T^2$	Z10.2, Z10.3, Z10.4, Z10.5, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10, Z10.12	—
P	power	ML^2T^{-3}	Z10.2, Z10.3, Z10.4, Z10.6, Y 10.7, Y10.9, Z10.12	—
Pr	Prandtl number	—	—	$Pr = \frac{c_p \mu}{k}$
q	dynamic or kinetic pressure	$ML^{-1}T^{-2}$	Y10.7	$q = \frac{\rho V^2}{2}$
q	quantity of heat per unit time; heat flow rate	ML^2T^{-3}	Z10.4, Z10.6, Y10.7, Y10.9, Z10.12	—
q	quantity of heat per unit mass (or per unit weight); specific quantity of heat	L^2T^{-2} (L)	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
Q	quantity of heat	ML^2T^{-2}	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	—
Q	volumetric flow rate	L^3T^{-1}	Z10.2, Z10.4	—
r	burning rate	LT^{-1}	—	$r = a(p_c)^n$
r	radius	L	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10, Z10.12	—
r	mixture ratio, instantaneous, oxidizer flow to fuel flow, by mass or weight	—	—	—
R	radius	L	—	alternate; r is preferred
R	range	L	Y10.7	—
R	gas constant, specific	$L^2T^{-2\theta^{-1}}$	Z10.9, Z10.6, Y10.7, Y10.10, Z10.12	$R = \frac{R_o}{M}$
R_o	gas constant, universal	$ML^2T^{-2\theta^{-1}}$	Z10.4, Z10.6, Y10.9, Y10.10, Z10.12	$R_o = MR$
Re	Reynolds number	—	—	$Re = \frac{LV\rho}{\mu}$

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
s	distance, linear	L	Z10.4, Z10.6, Y10.10	—
s	entropy, per unit mass (or per unit weight); specific entropy	$L^2T^{-2}\theta^{-1}$ ($L\theta^{-1}$)	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
S	surface area	L^2	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	—
S	entropy, in general or per mole	$ML^2T^{-2}\theta^{-1}$	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	—
S	suction specific speed	$L^{3/4}T^{-3/2}$	—	$S = \frac{n\sqrt{Q}}{(h_i - h_v)^{3/4}}$ used only when n—rpm Q—gpm $(h_i - h_v)$—net positive suction head above vapor pressure in feet
t	thickness	L	Z10.2, Z10.4, Y10.7, Z10.8	—
t	time	T	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Z10.12	general symbol. Also with appropriate subscript denotes instant of occurrence of a single event
T	temperature	θ	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	preferred; θ is alternate
T	torque	ML^2T^{-2}	—	—
u	velocity	LT^{-1}	Z10.4, Z10.6, Z10.12	—
u	velocity component along x axis	LT^{-1}	Z10.2, Z10.6, Y10.7, Y10.10	—
u	linear velocity of a point on a rotating body	LT^{-1}	Z10.2, Z10.4	—
u	internal energy, per unit mass (or per unit weight); specific internal energy	L^2T^{-2} (L)	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	—
U	internal energy, in general or per mole	ML^2T^{-2}	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	—
U	coefficient of heat transfer, over-all	$MT^{-3}\theta^{-1}$	Z10.4, Y10.7, Z10.12	—
v	velocity component along y axis	LT^{-1}	Z10.2, Z10.6, Y10.7, Y10.10	—
v	volume per unit mass (or per unit weight); specific volume	$M^{-1}L^3$ ($M^{-1}L^2T^2$)	Z10.4, Z10.6, Y10.7, Z10.12	—
V	velocity; resultant velocity	LT^{-1}	Z10.2, Z10.4, Y10.7, Y10.10, Z10.12	use u, v, and w as components
V	volume	L^3	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10, Z10.12	—
w	velocity component along z axis	LT^{-1}	Z10.2, Z10.6, Y10.7, Y10.10	—
w	web thickness	L	—	usually twice the burning distance

LETTER SYMBOLS FOR PRINCIPAL CONCEPTS

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
w	force of gravitational attraction; weight	MLT^{-2}	Z10.6	preferred; W is alternate $w = m\left(\frac{g}{g_c}\right)$
$\dot{w}$	change of weight per unit time; "weight flow" rate under constant gravitational attraction	MLT^{-3}	—	$\dot{w} = \dot{m}\left(\frac{g}{g_c}\right)$
W	force of gravitational attraction; weight	MLT^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.10, Y10.12	alternate; w is preferred
W	work	ML^2T^{-2}	Z10.2, Z10.6, Y10.9, Z10.12	—
α	angular acceleration	T^{-2}	Z10.2, Z10.3, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10	—
α	nozzle divergence half angle	—	Y10.7	—
α	thermal coefficient of linear expansion	θ^{-1}	Z10.4, Z10.6, Y10.9, Z10.12	—
β	thermal coefficient of volumetric expansion	θ^{-1}	Z10.4, Z10.6, Y10.10, Z10.12	—
β	nozzle convergence half angle	—	Y10.7	—
γ	specific weight	$ML^{-2}T^{-2}$	Z10.2, Z10.4, Z10.6	$\gamma = w/V$
γ	specific heat ratio	—	Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	preferred; k is alternate $\gamma = c_p/c_v$
δ	specific gravity	—	—	—
Γ_{ij}	over-all mass ratio	—		ratio of empty mass of jth stage to gross mass of ith stage
Δ	thermal coefficient of linear expansion	θ^{-1}	—	—
ϵ	cross-sectional area at station to cross-sectional area at throat	—	—	—
ϵ_c	nozzle-contraction area ratio	—	—	—
ϵ_e	nozzle-expansion area ratio	—	—	—
ϵ	linear strain	—	Z10.3, Y10.7, Z10.8	—
ϵ	ratio of radiant flux from a source to that for a black body of the same size and shape at the same temperature; total emissivity	—	Z10.4, Z10.6, Y10.7, Y10.9, Y10.10, Z10.12	$\epsilon = \phi/\phi_b$
ζ	payload ratio	—	—	ratio of payload mass of any stage to the gross mass of that stage
η	efficiency	—	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.9, Y10.10, Z10.12	—
θ	angle of radiation with normal to a surface	—	Z10.4	—
θ	temperature	θ	Z10.3, Z10.4, Z10.6, Y10.7, Y10.10	alternate; T is preferred

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
θ	temperature, thermodynamic	θ	Z10.4	used when necessary to distinguish from absolute temperature
κ_o	initial acceleration ratio	—	—	ratio of net initial acceleration to local acceleration of gravity
λ	nozzle-divergence loss factor	—	Z10.6, Y10.7	preferred concept; nozzle-divergence loss coefficient is alternate concept
λ	ratio of initial to final burning surface	—	—	—
λ	wave length; wave length of radiant energy	L	Z10.3, Z10.4, Z10.6, Y10.7, Y10.9, Y10.10	—
Λ	propellant ratio	—	—	ratio of propellant mass of any stage to gross mass of that stage
Λ_p	powerplant propellant ratio	—	—	ratio of propellant mass in propulsion system to gross mass of propulsion system
μ	Joule-Thomson coefficient	$M^{-1}LT^2\theta$	Z10.4, Z10.6	$\mu = \left(\frac{\delta T}{\delta p}\right)_H$
μ	viscosity, absolute	$ML^{-1}T^{-1}$	Z10.2, Z10.4, Y10.7, Y10.10, Z10.12	—
ν	frequency of radiant energy	T^{-1}	Z10.4, Z10.6, Y10.9, Y10.10	$\nu = c/\lambda$
ν	viscosity, kinematic	L^2T^{-1}	Z10.2, Z10.4, Z10.6, Y10.7, Y10.10, Z10.12	$\nu = \frac{\mu}{\rho}$
ξ	inert mass ratio	—	—	ratio of inert mass (structure, dry propulsion system, guidance, etc.) of any stage to the gross mass of that stage
ξ_p	propulsion system ratio	—	—	ratio of dry mass of propulsion system to gross mass of stage
π_K	temperature sensitivity of equilibrium pressure at a particular value of K (expressed in % per degree)	θ^{-1}	—	$\pi_K = \left(\frac{\delta \ln p}{\delta T}\right)_K$
π_p	temperature sensitivity of burning rate at a particular value of pressure (expressed in % per degree)	θ^{-1}	—	alternate; σ_p is preferred alternate concept is temperature coefficient of burning rate at constant pressure
σ_p	temperature sensitivity of burning rate at a particular value of pressure (expressed in % per degree)	θ^{-1}	—	preferred; π_p is alternate alternate concept is temperature coefficient of burning rate at constant pressure $\sigma_p = \left(\frac{\delta \ln r}{\delta T}\right)_p$
ρ	mass density	ML^{-3}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.10, Z10.12	—
σ	ratio of sliver weight to total propellant weight	—	—	—
σ	Stefan-Boltzmann constant	$MT^{-3}\theta^{-4}$	Z10.4, Z10.6, Y10.10, Z10.12	—

LETTER SYMBOLS FOR PRINCIPAL CONCEPTS

Symbol	Concept	Dimensions	Also Appears in ASA Publication	Remarks
σ	Thomá parameter	—	—	—
τ	time	T	Z10.4, Z10.6, Y10.7, Z10.12	—
ϕ	pump flow coefficient	L^2T^{-1}	—	$\phi = \frac{2gQ}{u^2}$
ϕ	radiant energy per unit of time for any area A; radiant flux	MT^{-3}	Z10.4, Z10.6, Y10.9	the radiant flux from a source ϕ_ω is sometimes called radiance $\phi = \int_o^{2\pi} J d\omega$
Φ_i	velocity ratio	—	—	ratio of velocity at burnout of the ith stage to the effective exhaust velocity of the propulsion system
Ψ	pump pressure coefficient	—	—	$\Psi = \frac{2g\Delta H}{u^2}$
Ψ	range ratio	—	—	$\Psi = \frac{R}{gI_s^2} = \frac{Rg_0}{c^2}$
ω	solid angle	—	Z10.4, Z10.6, Y10.7, Z10.12	steradians
ω	angular velocity	T^{-1}	Z10.2, Z10.3, Z10.4, Z10.6, Y10.7, Z10.8, Y10.10, Z10.12	—

Letter Symbols for Subscripts

(*Note: Letter symbols for principal concepts may also be used for subscripts*)

Subscript Symbols	Concept	Remarks	Subscript Symbols	Concept	Remarks
a	ambient		*D*	drag	
a	atmospheric		*e*	end	
a	local condition		*e*	nozzle exit	
a, *b*, ...	referring to different phases, states, or physical conditions, or to different substances		*e*	exit, discharge, exhaust	preferred; *d* is alternate
			E	denotes constant energy	
ad	adiabatic conditions		*f*	referring to formation	H_f is negative enthalpy of formation of product from its chemical elements
b	end of burning				
b	flight burnout condition		*f*	final	
b	black body or perfect radiator		*f*	friction	
b	burning of solid propellants		*f*	fuel	
			F	force, thrust	
c	combustion		*g*	referring to gaseous state	
c	combustion chamber				
c	coolant		*g*	pertaining to the gas generator	
c	cooled		*H*	denotes constant enthalpy	
d	discharge, exit	alternate; *e* is preferred			
d	dry		*i*	initial	

LETTER SYMBOLS FOR SUBSCRIPTS

Subscript Symbols	Concept	Remarks	Subscript Symbols	Concept	Remarks
i	injector	preferred; *j* is alternate	*S*	denotes constant entropy	
i	inlet		*t*	tank	
j	injector	alternate; *i* is preferred	*t*	throat	
j	jet		*t*	total; isentropic stagnation conditions	
l	referring to liquid state		*t*	turbine	
l	local		*T*	denotes constant temperature	
L	lift		*th*	theoretical conditions	
n	nozzle		*u*	usable solid propellant	
o	oxidizer				total propellant less slivers
p	pressure		*U*	denotes constant internal energy	
p	denotes constant pressure		*v*	vapor	
p	port or flow channel in solid propellant rocket		*v*	venturi	
			v	velocity	
p	propellant		*V*	denotes constant volume	
p	potential		λ	spectral or monochromatic values per unit of wavelength interval	
r	restriction				
s	slivers of solid propellant		0	referring to initial or reference conditions	
s	system				
s	suction	alternate; *i* (inlet) is preferred	0, 1, 2, . . .	referring to different points in an apparatus, process, cycle, etc.	
s	value of radiant flux emitted from a source				
s	static		∞	infinity reference condition	station far enough removed to be unaffected by local or transient changes
s	referring to solid state				

Letter Symbols for Superscripts

Superscript Symbol	Concept	Remarks
—	denotes average conditions	written directly over symbol; called "( )-bar"
.	denotes first derivative with respect to time	written directly over symbol; called "( )-dot"
..	denotes second derivative with respect to time	written directly over symbol; called "( )-double dot"
*	critical conditions corresponding to $M = 1$	

Jet Propulsion News

Alfred J. Zaehringer, American Rocket Company, *Associate Editor*
Norman L. Baker, Indiana Technical College, *Contributor*

Rockets and Guided Missiles

DENVER or Salt Lake City is being considered for the production site of Boeing's surface-to-air missile, BOMARC, IM-99. Marquardt Aircraft, producers of the ramjet powerplant for the IM-99, are searching for a production site near the proposed Boeing site.

● FALCON, GAR-98, separation tests made on F-102 models were run on the Navy's Inyokern SNORT track. In the meantime, a Convair F-102 was fitted with a camera to record the FALCON firing system. Although other interceptors may soon be armed with GAR-98 missiles, current tests indicate close dependence of missile and fire control system. FALCON currently tips the scale at 112 lb but will be 120 lb in newer, larger models soon to be produced.

● HONEST JOHN, the 762-mm rocket, is being assigned for service with Army batteries in the Far East. The rocket is already deployed in Europe.

● Production of LA CROSSE missile airframes will be by Glenn L. Martin. Present models of the missile are powered by a reciprocating engine. Cornell Aeronautical Laboratory developed the "beast" for the Army and Marine Corps.

● Announcement that Northrop Aircraft will build a guided missile plant in Texas will not involve the SNARK, SM-62, surface-to-surface missile program. Development and manufacture of the SM-62 will continue at Hawthorne, Calif. Indications are that Northrop's new missile, CROSSBOW, will be manufactured at the El Paso, Texas, plant. The P & W J-57 turbojet presently powers SNARK. The Allison J-71 was replaced to increase space for a larger guidance package. The J-57 has a lower fuel consumption than the J-71 which decreases fuel requirements without decreasing range. SNARK now uses solid propellant RATO bottles for zero length ATO. However, the 55 g accelerations being experienced are too large for the guidance package and may require the use of slower burning units of less thrust. New wing planform of SNARK resembles Douglas RB-66 twin jet bomber. Wings feature lower aspect ratio, leading-edge extensions for increasing surface, and external fuel cells.

● SIDEWINDER, the new Navy air-to-air missile is said to cost less than $1000 each in production. The missile was developed at Inyokern's NOTS; for comparison, estimated costs of the USAF FALCON and the Navy SPARROW are about $10,000 each.

● A rocket fire detector, the Fireye, is being evaluated by the USAF. The device by Electronics Corp. of America detects faultily fired or improperly released rockets. Palm-sized and weighing about $^1/_4$ lb., the heart of the system is a lead sulphide photocell. When the cell sees a rocket firing, the cell resistance is lowered. Through a constantly applied d-c voltage, the resistance drop is pulsed, sending a signal to a relay which actuates the rocket release mechanism.

● British Rolls-Royce firm has been given permission to manufacture North American Aviation rocket engines. Also to be exchanged is technical know-how under the recent Sandys-Wilson Collaboration Agreement on guided missiles.

● New guided missile test range is to be established by the British government in the Hebrides Island—about 70 miles west of Scotland. Main base will be South Uist Island with auxiliary bases on nearby islands.

● New rockets and installations were shown by the British Royal Aircraft Establishment. New 60-mm rockets had folding fins or were spin-stabilized with four canted nozzles. A 31-tube finned pod for wingtip use had a glass-reinforced plastic nose. There was a 7-tube plain pod and a 7-tube pod with spiral rails for the 25-lb rockets. Mark 12 is a 3-tier, rail-type rocket launcher carrying a dozen 12-lb ATG rockets.

● Australian target drone, the jet JINDIVIK, is to be made in the United States by East Coast Aeronautics.

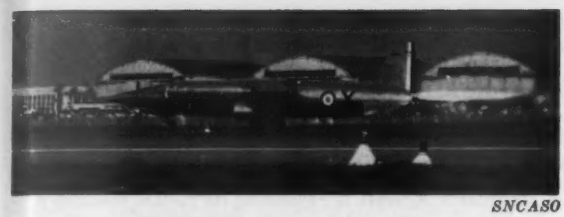
● VELVET GLOVE is a new Canadian air-to-air missile currently under development at Cold Lake, Alberta, and Valcartier, Quebec.

● Centraves Italiana has been granted a license to manufacture Oerlikon missiles. Rome's School of Air Engineering has received a U.S.A.F study contract to investigate high speed ballistics.

● Two new rocket weapons are under development by the French firm of Bureau Technique Zborowski. One is an infantry rocket-ramjet called the BTZ; range of the 33-lb missile (9-lb warhead) is about 3 miles. Another is called the OGRE I and is a longer range surface-to-surface missile with a liquid propellant system for take-off and a ramjet for sustaining cruise.

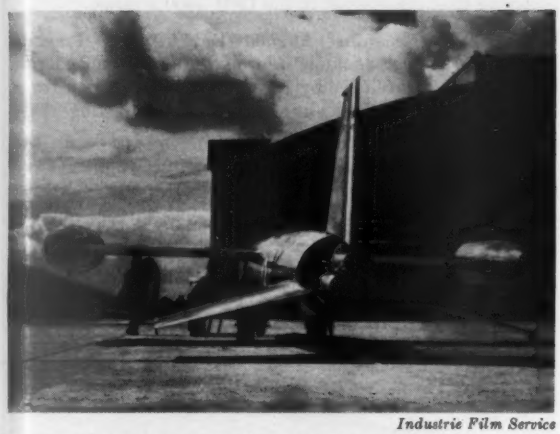
Rocket Aircraft. In the U.S.A., the Bell X-2 rocket-powered research aircraft is a radical change in design from the well known X-1A and X-1B aircraft being used at the present time. The most notable feature of the new craft is the Curtiss-Wright fully-throttleable rocket engine. This power plant develops 15,000 lb thrust and uses liquid propellants not named. Conventional landing gear has been replaced with a close-to-fuselage nose wheel and flat skids for the main landing gear. Elimination of conventional gear makes room for more fuel. The X-2 is expected to operate above the present altitude record of 90,000 ft set by Major Charles Yeager, and travel at speeds near 2000 mph. The first X-2 was destroyed by an explosion near Lake Ontario in 1953. A Bell test pilot was lost in the accident when an explosion blasted the X-2 loose from the B-50 carrier just before launching. Recently, a similar explosion in the Bell X-1A, just 70 seconds before release time, led to its destruction on the Mojave Desert. The X-1A was jettisoned from its B-29 mother plane for fear of destroying the B-29 and endangering the lives of its crew members. In France, the TRIDENT SO-9000, revealed at le Bourget airport in 1953, was powered by two wingtip-mounted jet engines. However, the craft was designed to use a rocket engine with turbojets installed only for auxiliary power. Cooperating with the SEPR Company, SNCASO undertook the development of rocket engines for the TRIDENT. In September 1954, the craft was first flown with its rocket engine. However, before the first rocket powered flight, more than 500 ground runups, either in test pits or with the rocket installed in the aircraft, were made in addition to some 60 rocket powered flights car-

EDITOR'S NOTE: The information reported in this Section has been selected from approved news releases originating with the Department of Defense, private manufacturers, universities, etc., and from published news accounts in journals and newspapers. The reports are considered generally reliable, although no attempt has been made to verify them in detail.



SNCASO

TRIDENT fires up its rocket engine



Industrie Film Service

View of TRIDENT shows three-cylinder rocket motor, stubby wings with tip jets

ried out in the ESPADON aircraft. Using only a fraction of its total power, the TRIDENT became supersonic in level flight and during the last stage of a climb in May 1955. Powerplant characteristics have not been revealed.

Research Rockets. Rockets are playing a significant role in U. S. research tracks and will be prominent during the forthcoming International Geophysical Year (IGY).

● SMART (Supersonic Military Air Research Track) is a new U. S. Air Force rocket sled track at Hurricane Mesa. The first run was made recently at the facility which is located near Zion National Park, Utah. Coleman Engineering Co. designed and constructed the track, the primary purpose of which is to develop emergency escape techniques from supersonic aircraft. Unlike other tracks, SMART was designed to provide free-flight conditions for test equipment and its recovery for further test. At the SMART facility, the test equipment is accelerated by a rocket sled and then catapulted over a 1500-ft cliff and lowering it by parachute to the desert floor where it is recovered. A new rocket sled, constructed by North American Aviation, is being used at the Inyokern NOTS test track. Flutter tests on the FJ-4 vertical tail are currently being tested. Meanwhile, the rocket sled at Edwards AFB, Calif., has established a new track record of 1608 fps (1100 mph). The 4300-lb sled was built by the Radioplane Co. of Van Nuys, Calif. The vehicle, which emitted a sharp sonic boom on its run, attained its peak speed in less than 5 sec after the start. The tremendous acceleration was attained using a two-stage system—one pusher sled with eight rockets which fired for 2.2 seconds, and then seven inboard rockets that were fired at the end of the pusher phase. The run was the first to hit 1000 mph and be recovered intact afterward.

Coleman Engineering

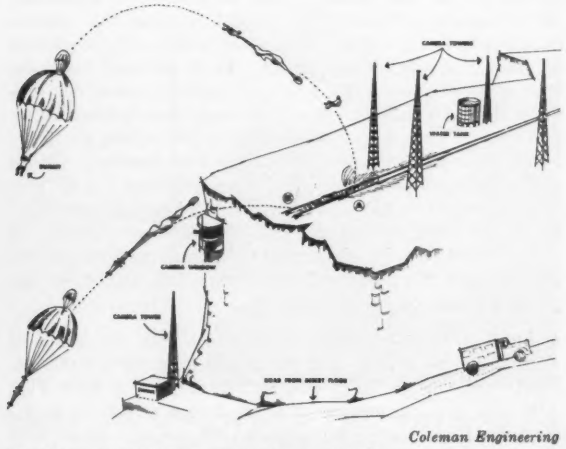
Geography of 2¼-mile long SMART facility

● New altitude record for a single stage rocket—180 miles—was set by the Aerobee-Hi at a recent firing over New Mexico. The rocket carried 150 lb of instrumentation.

● The Navy has launched solid propellant rockets vertically from high-flying jet aircraft in a recent series of tests. The rockets, known as ROCKAIR, were launched at 30,000 ft and reached altitudes of 17 miles. Cosmic ray studies were made in the first series of tests which took place at Chincoteague, Va., air station. Later tests will measure upper air temperatures and densities, ozone concentrations, and high altitude winds.

● During the forthcoming IGY (1957–1958) many research rockets are to be fired: 36 Aerobees (25 at Churchill, Canada, 11 at Alamogordo, N. Mex.), 37 ROCKOONS (Thule, Greenland; Churchill, Canada; Alamogordo, N. Mex.) plus an undisclosed number of aircraft launched rockets (Alaska, Newfoundland, and Greenland). British IGY activities will include the firing of solid propellant rockets from balloons. Instrumented rockets will be launched at 70,000 ft and will rise to 300,000 ft. The single-stage rockets will be fired from the Woomera, Australia, facility with an added possibility that rocket firings over the South Pole will also take place.

Satellites. The rocket vehicle required to place an unmanned satellite more than 200 miles above the earth will be a design more advanced in size, multiple-staging, and reliability than has been disclosed at the present time. The recent statement by the Aerojet-General Corp. that it could start immediate construction of a successful space satellite indicates significant advancements in missile developments.



Coleman Engineering

Operation of SMART. Rocket-propelled dummy is ejected at A, sled at B

The rocket vehicle for the satellite will be furnished by the Defense Department under usual production contracts. There have been no disclosures or possible contractors for the airframes and propulsion system. Convair has indicated its interest in participating in the space satellite program. Convair is a contractor for the ATLAS intercontinental ballistic missile which may be similar in size and configuration to the type of missile needed to carry the satellite. West Coast sources look on the ATLAS as a multistaged vehicle about 100 ft long and weighing over 100 tons. Convair is to develop tanks and fuselage, North American Aviation is handling the high thrust rocket engines, General Electric is dealing with the guidance system, while Ramo-Wooldridge and the Rand Corp. are doing systems work. Other firms such as Douglas Aircraft, Lockheed Aircraft, and Glenn L. Martin are actively engaged in satellite studies. Hard on the heels of the U. S. satellite announcement, the Soviets announced that they would have a larger satellite at a date much earlier than 1957. The U.S.S.R. announced a 241-mile rocket shot and a more recent 300-mile shot carrying animals. Earlier the Soviets had revealed that organizations had been set up to coordinate space research. These developments had been anticipated and it has even been reported that U. S. scientists were alerted to detect a possible Soviet satellite if and when it is established. Although Prof. Peter Kapitza is reported to be in charge of the Soviet satellite project, it is significant to note that hardware developments are under the control of Special Weapons Chief, General A. S. Yakovlev.

The Research Scene

DOWNWARD seat ejection of emergency escape is used on the Douglas X-3 research plane. In addition to ejection, the complete system includes a protective helmet, redesigned clothing, and improvement of oxygen supply. The seat is fin stabilized to 15,000 ft where the pilot is separated from the seat and lowered to the ground by conventional parachute.

● An Aerobee rocket firing on February 21, 1955, has provided much new information about the ultraviolet solar spectrum. During the entire flight of the Aerobee, which reached an altitude of 78 miles, a spectrograph was pointed at the sun. A continuous spectra of 1550 A and absorption lines to 1680 A were visible. In the ultraviolet range of 1817 to 977 A over 30 bright emission lines of 9 elements were identified. Previous rocket record was 3 emission lines (hydrogen and 2 magnesium lines).

● Much has been learned about the effect of cosmic radiation on living bodies at high altitudes. The Space Biology Branch of the Aero Medical Field Laboratory at Holloman Air Development Center, N. Mex., has found that cosmic radiation has no biological effect which could not be explained by prevailing altitude conditions. Facts gathered from the 1954 series of balloon flights have dispelled some of the previous fears of cosmic radiation. Animals were bombarded by particles at altitudes of 90–120,000 ft for as long as 35 hr. Findings were: (1) no nerve damage was observed; (2) no eye cataracts were developed; (3) no hair loss; (4) no permanent injuries; (5) only unusual effect noticed was that black rats developed white hair. Over all, says ARDC, "it appears that the biological effects of cosmic particles are no greater than the minimum values expected, except for the positive results on hair graying."

● Another ARDC project is concerned with the electrical charge nature of the air at altitudes of 60–100,000 ft. Plastic balloons are being sent aloft from Orlando AFB, Fla., with field strength meters. Electrical current flowing to the earth has been puzzling scientists for fifty years. At sea level the electrical field may be equal to 50 volts per ft, tapering off to about $^1/_2$ volt per ft at 100,000 ft.

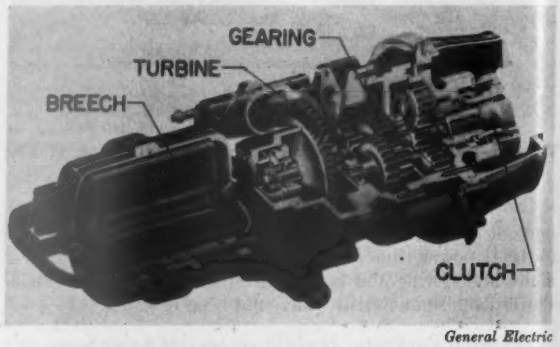
●NACA has revealed a design rule for minimizing drag on transonic aircraft. R. T. Whitcomb developed the simple area rule which has been employed on the Convair F-102A, Grumman F11F-1, and Chance Vought F8U-1 in the so-called "Coke Bottle" fuselage design. Transonic drag has been cut by as much as 60% and allows a speed gain of as much as 25%.

● Marquardt Aircraft is expanding its metals research program to include the development of ceramic and cermet materials for its ramjet program. Concern is to come up with materials that can operate in the 1200–2400 F range.

● RADOTT (Recording Angular Data Optical Tracking Theodolite) converts missile information into punched card or tape data. Developed by H. A. Wagner Co. of Van Nuys, Calif., the one-man device is soon to undergo testing at the Point Mugu installation.

Gas Generators

IN reality, any rocket engine is a gas generator. For rocket application, thrust is desired. In gas generators,



General Electric

Cutaway view of GE Model 7T-AS-12 Turbostarter

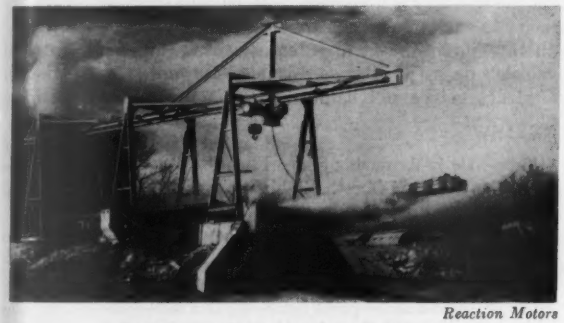
General Electric

Over-all view of G-E turbostarter. Tube at right ducts exhaust gases to turbine

the exhaust gases are put to work. These gases are used directly to operate turbines, pressurize fluids, or move objects. For these purposes the rocket motor has been modified to provide a compact, self-contained power pack. Although by no means complete, several interesting gas generators are presented here.

An early gas generator using a solid propellant rocket has been used by G-E to start the turbojets on the B-57 jet bomber. The electrically ignited charge burns at 500–1500 psi, producing exhaust gases at 1800–2000 F which in turn operate a turbine. Through gearing and a clutch, the starter turns engines to idling speed within seconds. G-E is to build a large number of these or similar starters for the Wright J-65 turbojet. Meanwhile, Olin Mathieson Chemical Corp. has contracted to supply 28,000 starter cartridges at about $20 each.

● A quarter-scale catapult powerplant test facility has been in operation at Reaction Motors. The Navy work was begun in 1946 and studied the use of liquid propellants to make high pressure gas for catapults. The project has gone through several experimental stages with gasoline and liquid oxygen, then gasoline-air-water, and finally to jet fuels, JP-4 and JP-5. The development went in stages from burning the fuels at 1500 psi, to 3000 and 4000 psi, and finally to 10,000 psi. It was later found that actual working pressures need not be this high. A full-scale catapult is now under construction.



Reaction Motors

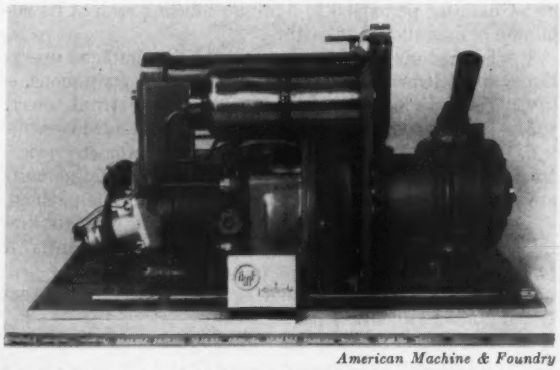
Liquid propellant rocket catapult test

● A gas generator using hydrogen peroxide has been developed by General Electric for use in missile propulsion systems. The gas generator weighs about 3.5 lb, is about 3-in. in diameter, about 4 in. long, and develops 850 jet horsepower. The generator produces a stream of high-temperature, high pressure steam, and oxygen.

General Electric

Small liquid propellant gas generator uses hydrogen peroxide

● Several types of gas generators are being produced by the Turbo Engineering Dept., American Machine & Foundry, Pacoima, Calif. All are essentially gas turbines driven by rocket motors. Performances are now in the 1–10 hp bracket. Monopropellants used for the rockets are ethylene oxide, and the alkyl nitrates. Other rocket developments include: A compressor driven by a rocket motor, air from the compressor is mixed with the rocket exhaust and burned at helicopter rotor blade tips; a rocket feed pump which operates at 100,000 rpm produces 800 psi pressure increase with a flow rate of 3 gpm and an impeller of about $^1/_4$ in; and a ram rocket where a rocket motor is mounted inside a ramjet to induce air flow and act as a flameholder.



American Machine & Foundry

Model 331 power pack delivers 4 hp for 30 sec. Weight is 22.6 lb

Developed for small scale use, an American Rocket Co. low-cost solid propellant gas generator supplies relatively cool and odorless, smokeless gas for auxiliary power in missile and commercial applications. Pressure ranges of 16–100 psia, operating temperatures of 2000 F, and operating times of up to 5 min. are claimed.

A unique gas generator has been developed as a chemical tube cutter for oil well use. McCullough Tool Co. and the Pennsylvania Salt Manufacturing Co. have come up with a charge which fires its gases into a halogen fluoride. The fluorides flow through orifices and impinge on the metal tube to be cut. Clean cuts are made by the rapid chemical action which takes place between the metal and the fluoride.

American Rocket Co.

Solid pill rocket delivers 25 psia for 5 min. Runs turbine with cool, smokeless exhaust

Space Flight Notes

Kurt R. Stehling, Bell Aircraft Corporation, Contributor

Astronautics

JOHN W. TOWNSEND, JR., Assistant Head of the Rocket Sonde Branch, Naval Research Laboratories, described in the September issue of *Electronics* his guesses on the "Electronic Aids for a Space Station" (see diagram). He emphasized the following features which would highlight the likely electronic operations of the small scientific IGY (International Geophysical Year) satellite:

1. Dry batteries, perhaps silver or mercury cells, would be used, being at this stage more reliable than "solar" batteries.
2. The vehicle, in its orbit above 250 miles, would telemeter data for perhaps 3 to 5 minutes during each of its 90-minute cruises about the earth.
3. Telemetering and tracking would be combined operations, with telemetering part time and tracking continuous.
4. Telemetering would need considerable electrical power.
5. Tracking could use low-power, narrow bandwidths.
6. Photon counters, geiger counters, magnetometers, electrostatic analyzers with various amplifiers, and scaling circuits are some of the expected instrumentation in satellite payload.
7. The telemetering transmitter's emission could be frequency modulated (fm), amplitude modulated (am), or pulsed.
8. The tracking and ground equipment may be conventional (and classified).
9. Computing mechanisms will have a big part in the accurate tracking of the missile and may detect the reduction (if any) in the orbital velocity.
10. Because of the high intrinsic resolving power of an optical system, optical tracking may prove more reliable and accurate than radar scanning.

——Although the immediate and proper goal of the space flight program is an orbital vehicle, studies of missile flights to the moon and planets have by no means been neglected. Also, research on such "exotic" schemes as photon propulsion has not been neglected; Eugen Sänger at the Forschungsinstitut für Physik der Strahlantriebe, Stuttgart-Flughafen, Germany, is studying methods of nuclear particle and light beam reaction propulsion. He is receiving financial support from an American aircraft firm for this work.

▶ The IGY satellite program will be beset by many technical problems which are part of any new missile development; however, the satellite itself will present a whole new group of headaches such as:

—orbit perturbation by the sun and moon (small).

—orbit perturbation caused by the oblate shape of the earth.

—collision with micrometeors, to say nothing of "macro" meteors!

—interaction with the magnetic field of the earth (perhaps not a negligible factor for a metallic body moving at 24,000 fps).

—cosmic ray and solar radiation damage to tube filaments and transistors.

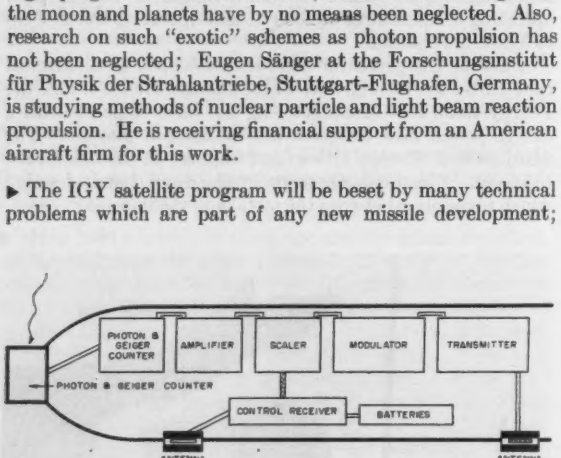
—maintenance of a heat balance within the satellite.

—a means of reliable attitude control, either by gyroscopes, groups of flywheels, or control jets.

—recognition of its instantaneous altitude and attitude. This is necessary for proper measurement and interpretation of cosmic ray data, etc.

—circumvention of telemetering signal attenuation by the ionosphere.

It is commonly assumed that the satellite will "burn up" by aerodynamic friction upon re-entry into the atmosphere. If vehicle recovery is necessary, then various proposed schemes, such as a coating of plastic material which forms a poorly conducting liquid film at high temperatures, might prevent the vehicle's destruction while it is decelerating to slower speeds. Destruction by aerodynamic forces then becomes a possibility.



A possible arrangement of the instrumentation for the IGY satellite

REVIEW

"Methods of Achieving Space Flight" (Wege zur Raumschiffahrt), by Hermann Oberth. Published by R. Oldenbourg, Berlin, 1929. Now out of print.

With the motivations of the announced space flight program and the arrival in the United States of Hermann Oberth, a brief review of the II, III, and IV parts of his famous classic will be given in this and subsequent issues of JET PROPULSION.

Part II—Physical-Technical Problems, chapters 5–8.

Oberth describes in some detail the thermodynamic conditions existing in a rocket thrust chamber. He lists the symbols and the nomenclature for such terms as exhaust velocity (c) specific heat ratios, chamber pressure (P_0), etc. It is interesting to note that today, almost 30 years later, an American Standards Association committee has finally been established for the purpose of standardizing rocket symbols.

The theory of the nozzle is explained, much of it based on existing turbine nozzle theories. On page 31 is a description, based on a suggestion by Professor Proll of Hamburg, of a ducted rocket. Proll suggested that the nozzle act as a "diffuser," with the ability to suck in ambient air. Oberth correctly stated that this would reduce the exhaust velocity but would increase the thrust, a conclusion based on considerations of the air entrainment process.

The theory of the effect of the mass ratio of a rocket vehicle is presented. He defines mass ratio as M_0 or initial mass divided by "burned-out" mass, M_1. Oberth undoubtedly received a stimulus from Goddard's early works which emphasized the importance of this ratio for a sounding or ballistic rocket missile. In Chapter 8 is explained the term "propulsion efficiency"; also it is shown that the more quickly a vehicle can be accelerated to some arbitrary final velocity the more useful work can be done by the propellant. On the other hand, he states, if the rate of acceleration is too rapid and the burn-out velocity is too high, then air drag becomes a significant factor.

(*Continued on page 665*)

EDITOR'S NOTE: This new section of the JOURNAL has been incorporated as a regular monthly feature in response to many requests from ARS members. Mr. Stehling will offer news and comments on space flight and on such related topics as upper atmosphere research, astronomical findings, and aeromedical developments. From time to time, articles and lectures that have appeared elsewhere will be reviewed. Suggestions for subjects worthy of presentation will be welcome.

25th Anniversary Annual Meeting to be Held in Chicago, November 13–16

To include 11 technical sessions, Space Flight Symposium, Forum on Rocket Symbols; Kaplan of IGY, Dinner Speaker

THE ARS 25th Anniversary Annual Meeting will be held in conjunction with the ASME Diamond Jubilee Meeting, November 13–16, at the Conrad Hilton Hotel, Chicago.

The ARS Annual Business Meeting will take place on Monday evening, November 14, at 8:00 p.m. The Section Luncheon is scheduled for Tuesday, November 15 at 12:00 noon.

Awards and Fellowships to be Presented

Acting on the recommendations of the Awards Committee, the ARS Board of Directors has named the following recipients of awards for 1955:

Robert H. Goddard Memorial Award (for outstanding work in liquid propellants): Lt. Col. E. N. Hall, Western Development Div., ARDC.

C. N. Hickman Award (for outstanding work in solid propellants): F. S. Miller, Aerojet-General Corp.

G. Edward Pendray Award (for literary contribution to rocket and jet propulsion field): Walter Dornberger, Bell Aircraft.

James H. Wyld Memorial Award (for outstanding application of rocket power): Lt. Col. John P. Stapp, Holloman Air Development Center.

ARS Astronautics Award (for outstanding contribution to space flight): Wernher von Braun, Redstone Arsenal.

ARS Student Award: Richard W. Foster, Purdue University.

Chairman of the Awards Committee was Robert C. Truax. On the Committee were H. N. Toftoy, T. F. Reinhardt, and W. E. Zisch.

Named as Fellows were the following:

A. B. Cambel, Northwestern Univ.
B. L. Dorman, Aerojet-General Corp.
Robert H. Jewett, Boeing Airplane Co.
R. Healy, North American Aviation, Inc.
Rear Admiral J. H. Sides, Office, Chief of Naval Operations
E. G. Uhl, Glenn L. Martin Co.
Paul Winternitz, New York University

The Awards and Fellowships will be presented at the Honors Night Dinner on Wednesday evening, November 16. Principal speaker at the Dinner will be Joseph Kaplan, Chairman of the U. S. National Committee for the International Geophysical year 1957–1958. He will discuss the proposed use of rockets and satellites in the IGY program.

The program follows:

MONDAY, NOVEMBER 14

9:30 a.m. Session IA

THERMODYNAMICS AND HEAT TRANSFER

Chairman: Maurice J. Zucrow, Purdue University
Vice-Chairman: S. V. Gunn, North American Aviation, Inc.

High Capacity Turbojet-Powered Heat Exchanger, by J. H. Schmidt, Marquardt Aircraft Co. (244-55)

Forced Convective Heat Transfer and Pressure Drop Characteristics of White and Red Fuming Nitric Acids—Problems with Scale Formation, by H. Wolf, F. L. Gray, and B. A. Reese, Purdue University (255-55)

Heat Transfer Characteristics of a Rocket Motor Burning White Fuming Nitric Acid and Jet Engine Fuel at High Combustion Pressures, by D. E. Robison, D. G. Elliott, and C. F. Warner, Purdue University (256-55)

The Vortex Tube as a True Free Air Thermometer, by Jack C. Hedge, Armour Research Foundation (243-55).

9:30 a.m. Session I-B

ROCKET SYSTEMS STABILITY

Chairman: R. W. Illman, Boeing Airplane Co.

Mathematical Analysis of the Sensitivity of a Propellant Feed System to Rocket-Induced Vibration, by C. M. Ablow, Stanford Research Institute (251-55)

Measurement of the Sensitivity of a Propellant Feed System to Rocket-Induced Vibration, by E. M. Gardiner, Boeing Airplane Co. (252-55)

Electronic Analog Simulator Study of a Bi-Propellant Liquid Rocket System, by G. G. Setterlund, Boeing Airplane Co. (253-55)

A Theory of Rocket Combustion Dynamics Including Effects of Combustion Chamber Gas Temperature, by L. Steg, Cornell University (254-55)

2:30 p.m. Session II-A

COMBUSTION

Chairman: H. A. Fremont, General Electric Co.
Vice-Chairman: P. S. Myers, Univ. of Wisconsin

Flame Stabilization in High Speed Streams, by J. J. Zelinski, R. E. Walker, and P. Rosen, Applied Physics Laboratory, The Johns Hopkins University (271-55)

Reliability of Combustion Efficiency Evaluation for Jet Propulsion Based Upon Aerodynamic Measurement of Combustion Temperature, by Gilbert S. Bahn, Marquardt Aircraft Co. (272-55)

Flame Stabilization Resulting from Cyclonic Flow of Mixtures of Natural Gas and Air, by Lyle F. Albright, University of Oklahoma and Lloyd G. Alexander, Carbide and Carbon Chemicals Co. (273-55)

2:30 p.m. Session II-B

MATERIALS AND DESIGN

Chairman: C. M. Beighley, Aerojet-General Corp.
Vice-Chairman: Heinz Mueller, Bell Aircraft Corp.

Special Ceramic Materials of Construction for Rocketry, by H. M. Killman and W. L. Wroten, The Carborundum Company (261-55)

Fiberglas Reinforced Plastic as a Rocket Structural Material, by S. M. Breslau and K. D. Miller, The M. W. Kellogg Co. (262-55)

Evaluation of Some New Materials for Missile and Powerplant Applications, by A. V. Levy, Marquardt Aircraft Co. (263-55)

8:00 p.m. Annual Business Meeting

TUESDAY, NOVEMBER 15

9:30 a.m. Session III-A

SOLID PROPELLANTS

Chairman: C. E. Bartley, Grand Central Rocket Co.
Vice-Chairman: W. F. Cramer, Armour Research Foundation

Some Effects of Weapons Concept on Rocket Design, by Howard M. Kindsvater, Lockheed Aircraft Corp. (257-55)

The Use of Weapons Systems Engineering Concepts in the Design of Solid Propellant Missile Power Plants, by H. L. Thackwell, Jr., Grand Central Rocket Co. (258-55)

A Quasi-Morphological Approach to the Geometrical Design Aspects of Propellant Charges, by Jack M. Vogel, Ramo-Wooldridge Corp. (259-55)

Observations on the Irregular Reaction of Solid Propellant Charges, by Leon Green, Aerojet-General Corp. (260-55)

Film: Criteria and Service Conditions Resulting in U.S.A.F. Solid Propellant Rocket Engine Specification Requirements—a film prepared by the Power Plant Laboratory, Wright Air Development Center, Air Research and Development Command, and narrated by W. C. Fagan of the Power Plant Lab., Dayton, Ohio

9:30 a.m. Session III-B

AERODYNAMICS

Chairman: A. H. Flax, Cornell Aeronautical Lab.
Vice-Chairman: H. S. Glick, Cornell Aeronautical Lab.

Aerodynamics in a Highly Rarefied Atmosphere, by S. A. Schaaf, University of California (267-55)

Hypersonic Studies of the Leading Edge Effect on the Flow Over a Flat Plate, by A. G. Hammitt and S. M. Bogdonoff, Forrestal Research Center, Princeton University (268-55)

Aerothermodynamic Problems of Hypersonic Flight, by A. Hertzberg, Cornell Aeronautical Lab. (269-55)

Hypersonic Flight: Some Aerodynamic Considerations, by J. S. Isenberg, Bell Aircraft Co. (270-55)

12:00 p.m. Section Luncheon

2:30 p.m. Session IV-A

LIQUID PROPELLANTS

Chairman: J. L. Sloop, Lewis Flight Propulsion Lab., NACA

Vice-Chairman: Gerald Platz, Armour Research Foundation

Test Methods for Monopropellants, by P. F. Winternitz, New York University (236-55)

Storability of Nitric Acid, by D. M. Mason, Jet Propulsion Lab., CalTech (237-55)

Properties of Ozone by Gerald M. Platz, Armour Research Foundation (238-55)

Rocket Performance Measurements with Streak Photography, by Marcus F. Heidmann and Carmon M. Auble, NACA, Lewis Flight Propulsion Lab. (239-55)

Optimum Ratio of Propellants for a Liquid Bi-propellant Rocket System Operating Within a Mixture Ratio Tolerance, by Joseph Brousseau, Boeing Airplane Co. (240-55)

2:30 p.m. Session IV-B

CONTROL SYSTEMS

Chairman: D. E. Noble, Motorola, Inc.

Vice-Chairman: Irving Koss, Motorola, Inc.

Transistor Reliability: 1955, by Donald Barnes, Bureau of Ships (275-55)

Automatic Production of Electronic Equipment, by Clay Lafferty, Armour Research Foundation (248-55)

Selectivity Through Mechanical Resonance, by Roy Altman, Motorola, Inc. (249-55)

2:30 p.m. Session IV-C

HIGH ALTITUDE RESEARCH

Chairman: Kurt R. Stehling, Bell Aircraft Corp.

Vice-Chairman: Krafft Ehricke, Convair, a Div. of General Dynamics Corp.

Application of the Satellite Vehicle, by R. P. Haviland, Ramo-Wooldridge Corp. (264-55)

Transfer Between Circular Orbits, by Derek F. Lawden, College of Technology, Birmingham, England (265-55)

Sun Follower for High Altitude Sounding Rockets, by D. D. Terwilliger, Aircraft Armaments, Inc. (266-55)

4:00 p.m.

FORUM ON PROPOSED AMERICAN STANDARD LETTER SYMBOLS FOR ROCKET PROPULSION

Chairman: Robertson Youngquist, Reaction Motors, Inc.

Secretary: J. Preston Layton, Forrestal Research Center, Princeton University

WEDNESDAY, NOVEMBER 16

9:30 a.m. Session V-A

SPACE MEDICINE

Chairman: Hubertus Strughold, U.S.A.F. Dept. of Space Medicine, Randolph Field

Climatization of Animal Capsules for Upper Stratosphere Balloon Flights, by Major D. G. Simons, Chief, Space Biological Branch, Aeromedical Field Laboratory, Holloman Air Development Center (241-55)

The Medical Problems Involved in Orbital Space Flight, by Hubertus Strughold, U.S.A.F. School of Aviation Medicine, Randolph Field (242-55)

9:30 a.m. Session V-B

INSTRUMENTATION AND TESTING

Chairman: Edward Cartotto, North American Aviation, Inc.

Vice-Chairman: T. E. Meyers, North American Aviation, Inc.

The Turbojet Exhauster Story, by T. E. Hudson, Marquardt Aircraft Co. (245-55)

The Solution of Two-Dimensional Steady State Heat Transfer Problems by the Use of Electrically Conductive Paper, by Leo E. Dean, North American Aviation (246-55)

Launching and Handling of Large Liquid Fueled Guided Missiles, by T. M. Pettey, Jr., General Electric Co. (247-55)

Statistical Evolution of Instrumentation for Rocket Engine Research Testing, by J. M. Zimmerman, North American Aviation, Inc. (250-55)

2:30 p.m. Session VI

SPACE FLIGHT SYMPOSIUM

Chairman: D. C. Romick, Goodyear Aircraft Corp.

Vice-Chairman: R. J. Couts, Goodyear Aircraft Corp.

Panel Members

Krafft A. Ehricke, Convair

Andrew G. Haley, Haley, Doty & Wollenberg

Herman Lagow, Naval Research Laboratory

Norman V. Petersen, Sperry Gyroscope Company

William G. Purdy, Glenn L. Martin Co.

S. Fred Singer, Univ. of Maryland

Kurt Stehling, Bell Aircraft Corp.

Ernst Stuhlinger, Redstone Arsenal

7:00 p.m. 25th Anniversary Honors Night Dinner

Toastmaster: R. W. Porter, President, ARS

Speaker: Joseph Kaplan, Chairman, U. S. National Committee, International Geophysical Year

Los Angeles Meeting Attended by Over 500

By John W. Herrick

Rheem Mfg. Co., Downey, Calif.

THE largest regional meeting ever held by the American Rocket Society closed on September 21 with the showing of eight special rocket movies to an overflow audience at the Hotel Statler in Los Angeles. This culminated three days of outstanding events—speeches by the Hon. Trevor Gardner, Dan Kimball, and Donald Douglas, Jr.; five technical sessions at which 23 papers were presented, and three tours.

Meeting Chairman William Cecka announced that more than 500 registered during the meeting, while public events (movies and Disney tour) each drew almost 700.

Gardner Emphasizes Reliability

In a major speech at the Meeting Banquet, Assistant Secretary of the Air Force Gardner reviewed progress in missile technology in the past 11 years, giving considerable credit to ARS members and to the Society. He said: "One of the most difficult problems lies in the evolution of a guided missile of sufficient reliability to replace the priceless human ingredient—the unique combination of intellect, 20/20 vision, and well-coordinated hands and feet." He concluded firmly with the remark that the Air Force would tolerate no cuts in its budget if these cuts jeopardized the missile and aircraft program.

Gardner was introduced by president R. W. Porter, who also introduced Chester McCloskey, president of the Southern California Section; Noah Davis, national vice president· national directors Andrew Haley, Roy Healy, and George Sutton; guests Col. J. E. Johnston, Los Angeles Ordnance District; Major Robert Crawford, Office of Scientific Research; and Commander E. Quarterman, 13th Naval District; section vice president Richard Geckler; meeting chairman William Cecka; program chairman Robert Cornog; and James J. Harford, executive secretary.

Kimball Offers "100 Years of Peace"

At the first luncheon, Dan Kimball, president of Aerojet-General, explained to 200 listeners how the nation could maintain peace in this country and limit the spread of aggression abroad. The ex-Secretary of the Navy spoke of the need for long-range planning in armed preparedness, pointing out that even 100 years of peace was possible if America retained its military superiority.

He was introduced by Dr. McCloskey.

Douglas on Systems Concept

Skill and experience brought by the aircraft industry to the manufacture of guided missiles go far beyond the single ability to produce objects that fly, Donald W. Douglas, Jr., vice president-Military Relations of the Douglas Aircraft Company, told a second-day luncheon audience of 200.

"It is the experience we have had in managing complex systems that must be given first importance," he stated, drawing a parallel between the large number of components that make up airplanes and missiles. He said the aircraft industry is further advanced in the large-scale use of computers than any other industry. Production skills (such as quality control) and follow-up through trained service departments also were listed as important contributions of the aircraft industry to missile manufacture.

Feature Events Well Received

The classified tour through Aerojet-General, well-known manufacturer of solid and liquid propellant rockets, was taken by 102 members. The program opened with a showing of the classified film "Rocket Power for Defense." Then the group was conducted through the many facilities, test cells, and buildings of the plant.

An unclassified tour to Morris Dam, through the courtesy of the U. S. Naval Ordnance Test Station, was made by approximately 35 members. Facilities at this test site for the Underwater Ordnance Department are located in the San Gabriel mountains. The variable-angle torpedo launcher, a unique structure for launching underwater missiles in simulation of air-launched conditions, was shown and explained to the visiting members. The small-caliber test range, the sonic barge for underwater-sound measurements, test pits, and the underwater cableway were also viewed.

Preview at Disney Studios

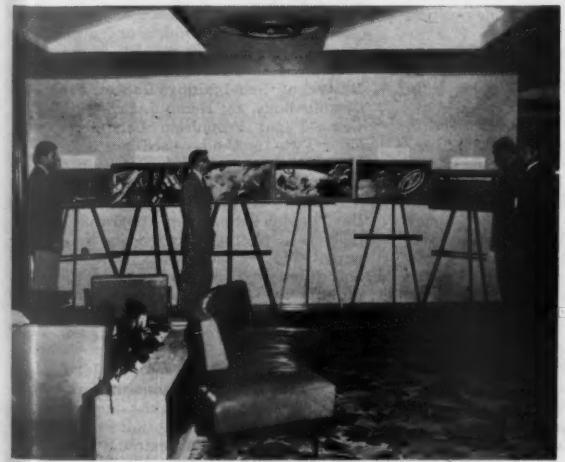
Top entertainment feature occurred Monday evening when over 600 members,

Men, Missiles, Meetings at Los Angeles . . .

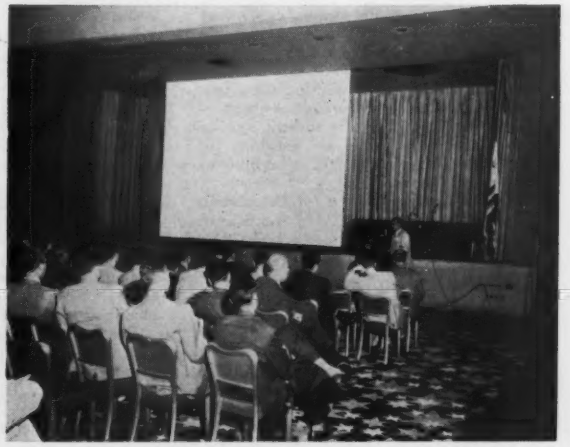
Luncheon speaker Donald Douglas, Jr (center) is flanked by (left to right) J. J. Harford, Robert Cornog, Leland Cole, Andrew G. Haley, R. W. Porter, chairman William J. Cecka, Noah S. Davis, Chester M. McCloskey, Paul Castenholz, and Elmer P. Wheaton

Speakers table at luncheon addressed by Dan A. Kimball includes (left) George P. Sutton, Harford, Cecka, Porter, McCloskey; and (right) Kimball, Davis, W. H. Taft, Cornog, and Roy Healy. Section president McCloskey introduced the speaker

Exhibits were furnished by local industry and military establishments. They included Nike, Aerobee, Nativ, Sparrow, and Falcon missiles; rocket-powered test sled, bipropellant engine, and armament rockets



Chelsey Bonestell original paintings were displayed in hotel lobby, depicting artist's conception of space flight scenes



One of five technical sessions held was this one, showing author Krafft Ehricke delivering paper on "satelloid"

wives, guests, and officials journeyed to the Disney Studios at Burbank. A special screening of the color print of "Man in Space" was presented. Explanations on filming techniques, and a talk by Heinz Haber (one of Disney's advisors) enhanced the presentation. Portions of the unreleased television movie "Man and the Moon" were shown, some footage still in rough pencil form. The punch-line of the evening was offered as a surprise for all the rocket and astronautical authorities in the audience—the first "views" of the other side of the moon, the side never visible from Earth. This sequence was so effectively and accurately simulated with a large moon-model that all present were noticeably impressed. Models of space ships and the other exhibits in the lobby attracted considerable attention.

Rocket Exhibits at Hotel

An exhibit of missiles, rockets, and Chesley Bonestell paintings was set up at the hotel throughout the meeting. The NIKE antiaircraft guided missile, the Aerobee sounding rocket, the Nativ research rocket, the Cook-North American rocket test sled, the Navy Mighty Mouse air-to-air rocket, the RMI 6000 Series liquid propellant rocket engine, and an RMI turbopump assembly were exhibited. The two latter were courtesy of Edwards Air Force Base.

There was also an interesting display of the 2.75-in. folding-fin rocket, the Mighty Mouse, set up by personnel of the U. S. Naval Ordnance Test Station, China Lake. A working assembly of the fins and actuator piston was attached to a large plastic panel.

Two modern missiles, the Falcon and the Sparrow, were shown to the general public for the first time. The Falcon GAR-1, a guided air-to-air rocket, was set up by Hughes Aircraft Co. The Sparrow air-to-air guided missile, developed by Sperry, was exhibited by the U. S. Naval Air Missile Test Center, Point Mugu.

SUMMARY OF TECHNICAL SESSIONS

ANALYSIS (I)

Evaluation of Reliability in Product Development. Myron Lipow and Richard D. Geckler (213-55), Aerojet-General, presented a mathematical method of estimating "instantaneous reliability." This is a value obtained from test results at any time during a period of rapid change in a product development program. Reliability was assumed to be a random variable that could be described by a beta distribution function. Parameters are dependent upon test quantity and observed reliability in several sets of tests. Calculations give an estimate of "instantaneous reliability" and instantaneous rate of increase in reliability.

Hydraulic-Analog Method for Calculation of Thermal Gradients. Eldon L. Knuth and Emerson L. Kumm, Aerophysics Development Corp. (214-55), described a one-dimensional hydraulic analog computer and results obtained from it when simulating the transient heat flow in selected materials. The equipment was proved to be of significant value in measuring the rate of heat transfer o. a hot gas flowing through a complex system. It makes possible rapid empirical solutions of the heat-transfer characteristics of many different shapes and materials, in a practical manner.

Analysis of Thrust Chamber Performance Data, by Daniel C. Schiavone, Bell Aircraft Corp. (215-55). A straightforward statistical method for calculating (also determining by convenient charts) the expected errors in computed values of rocket-engine performance was presented. The basic principles of the propagation of errors was applied, considering inherent instrumentation errors.

Generalized Solution of the Theoretical Specific Thrust in a Rocket Motor for the C-H-N-O-F Atomic System, by Mary S. Morgan, J. Silverman, and W. T. Webber, North American Aviation (216-55). Study was based on the premise that only seven variables are needed to completely determine the theoretical I_{sp} of the carbon-hydrogen-nitrogen-oxygen-fluorine system. It was found that the majority of useful rocket propellants lies within that system. Curves of theoretical I_{sp} vs. oxidation ratio for various hypothetical compositions and heats of formation, under chosen conditions, were presented.

Generalized Theory of the Optimum Thrust Programming for the Level Flight of a Rocket-Powered Aircraft, by Placido Cicala, Politecnico di Torino, and Angelo Miele, Purdue University (217-55). This paper basically presented the outline of a promising method for optimizing the burning (or thrust) program for a rocket-propelled vehicle that maintains horizontal flight. There was an underlying feeling that the two highly mathematical theories presented would class previously published work as special cases. The first theory discussed was based on Green's theorem; the second theory resulted from application of the Euler-Lagrange equations. A concept of index value was introduced to an American audience for the first time. It was claimed that this index value would permit the solution of rather complex variational problems without substantial difficulties.

COMBUSTION (II)

The Application of Radiation Measurement Techniques to the Determination of Gas Temperatures in Liquid-Propellant Flames, by Carmon M. Auble and Marcus F. Heidmann, NACA Lewis Flight Propulsion Laboratory (218-55). Radiation temperature measurements based on a two-color method were reported. The radiation intensities of a liquid-oxygen and heptane-turpentine flame at two distinct wavelengths were measured by apparatus comprised of a spectrometer with photomultiplier tubes and a tungsten lamp, for a standard comparison source. It was found that these measurements were most useful for very fast qualitative observations of absolute temperatures, as a function of flame position and time.

Experimental Aspects of Rocket System Stability, by Y. C. Lee, A. M. Pickles, and C. C. Miesse, Aerojet-General Corp. (219-55). Considered transmission of pressure waves traveling in the propellant lines in relation to oscillatory combustion. An investigation was reported wherein the damping characteristics of several stabilizing devices (stability orifices, inductive venturis, flexible hose, and distributed capacitance cores) and of different propellants were determined experimentally. The relative effects were compared by observing the change in decrement rates of the resultant pressure oscillations in the combustion chamber of an operating engine.

Solution of Thermochemical Propellant Calculations on a High-Speed Digital Computer, by A. J. Donegan, Jet Propulsion Laboratory, C.I.T., and M. Farber, Aerojet-General (220-55). A three-cycle iterative scheme for the simultaneous solution of the various items involved in chemical combustion phenomena was reported. The paper described the thermochemical, mathematical, and coding aspects of the problem of carrying out performance calculations on rocket propellants on a high-speed digital computer.

Experiments on the Burning of Single Drops of Fuel, by Martin Goldsmith of Rand Corp. (221-55). This paper discussed experiments performed on measuring mass rate on consumption of single droplets of liquid fuel. Single droplets were suspended on a quartz filament and burned under various ambient conditions: increased oxidizer concentration, increased pressure, and elevated temperature. The influence of these conditions on mass burning rate was studied. Comparisons with theoretical calculations were made.

COMBUSTION (III)

Determination of the Effective Specific Heat and True Gas Composition in a Rocket Motor, by Paul J. Blatz, Aerojet-General Corp. (222-55), was a highly theoretical treatment of effective specific heat and the means of computing this property in a system in which a chemical reaction is taking place. The method is said to determine the true composition of the gas in a rocket combustion chamber at a relative error of less than 1 per cent.

The Effect of a Variable Evaporation Rate on the Ballistics of Droplets, by C. C. Miesse, Aerojet-General Corp. (223-55). An analysis of the effect of the variation of evaporation, with Reynolds number, of a liquid droplet on its velocity and diameter variations was conducted. The effect was analyzed by consideration of the ballistic and the evaporation (Frössling's) equations simultaneously. The results indicated that the analysis of constant evaporation rate will be valid for high values of the ratio of viscosity to still-air evaporation rate, but should be modified for lower values.

Interference Effects During Burning in Air for Two Stationary *n*-Heptane, Ethyl Alcohol, and Methyl Alcohol Droplets, by J. F. Rex, A. E. Fuhs, and Stanford S. Penner, Guggenheim Jet Propulsion Center, C.I.T. (224-55). Experiments conducted with two closely spaced fuel droplets burning in air raised some doubt on the practical value of combustion calculations based on burning single droplets and simple droplet arrays. Droplet interference and interaction were investigated using droplets suspended on thin quartz fibers in static air; determination of the evaporation constant and the flame shapes was made. Surprising behavior was reported. Within limits of experimental accuracy, the evaporation constant was invariant, with time, for two closely spaced fuel droplets and also for the center droplet of a five-droplet array.

Two Methods for Measuring Ignition Delays of Self-Igniting Rocket Propellant Combinations, by Dezso J. Ladanyi, NACA Lewis Flight Propulsion Laboratory (225-55). Two methods used at the Lewis Laboratory in determining ignition delay of hypergolic propellant combinations were described. A laboratory setup, known as the "modified open-cup apparatus," and a high-speed photography system on a transparent-side rocket engine were explained and illustrated by slides. The fuel was rapidly introduced into the oxidizer, with the open-cup apparatus, and three simultaneous measurements of ignition delay were usually recorded.

Testing 100,000 Horsepower Jet Engines, by Leigh E. Dunn, Marquardt Aircraft Co. (226-55). This paper points out that rocket engines are not the only units that develop violent aspects under extreme test condi-

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From earliest cannon-carrying fighters to the most advanced guided missile weapons systems, Bell Aircraft has pioneered for 20 years in the design and production of new armament for our nation's security.

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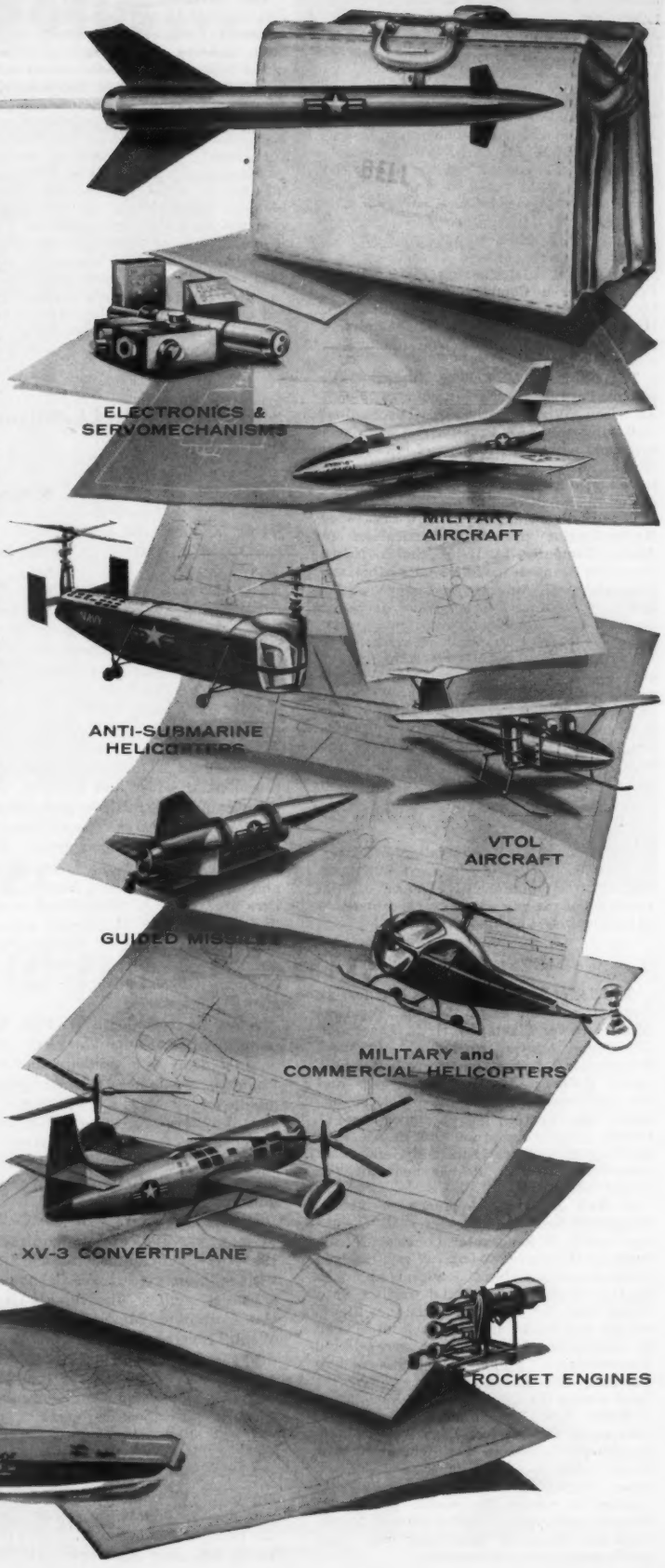

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tions. Instrumentation which acquired approximately 80,000 data points per week at Marquardt was reported.

FIELD PROBLEMS (IV)

Missile Flight Safety Considerations at White Sands Proving Ground, by George L. Meredith and Donald I. Thompson, Operations Branch, WSPG (227-55). The intent, methods, and techniques utilized to stop the flight of a "wild" missile were reviewed. The graphs of impact-range capability for the Corporal and the Aerobee were screened; plotting board grids of the Viking and an impact predictor were also illustrated.

Operational Analysis of a Field Support Program for a Complex Weapon System, by Joseph Dresner and Albert Shapero, Hughes Aircraft Co. (228-55). Considers provisioning, maintaining, and handling a weapons system.

The Problem of Rocket Engine Component Testing, by F. A. Jennings, North American Aviation (229-55). The method utilized at the NAA Propulsion Center was explained with chart forms and information records shown on the screen. Results obtained from a typical test program were presented.

Perturbation Analysis of Low-Frequency Rocket-Engine System Dynamics on an Analog Computer, by B. M. Smith, North American Aviation (230-55). A mathematical model of a liquid-propellant rocket engine system was formulated and then simulated on an analog computer. Perturbation equations and a computer circuit were developed for a turborocket system which maintained thrust control by sensing thrust-chamber pressure and manipulated a turbine throttle valve, providing an input variable. The engine components were linearized, limiting the use of this analytical method to the equilibrium-conditions region. The computer model will behave like an actual rocket engine system to the extent that parameters assigned to the components represent the true conditions.

Missile Range Instrumentation, by James P. Judin, U. S. Naval Ordnance Test Station (231-55). A comprehensive paper on the problems of making adequate measurements of missiles in test flights was presented.

GENERAL (V)

The Use of Weapons Systems Engineering Concepts in the Design of Solid Propellant Missile Power Plants, by H. L. Thackwell, Jr., Grand Central Rocket Co. (232-55). Demonstrates how a solid-propellant rocket motor designer attacks the problems and the performance parameters which he has under his control. Shows importance of closely integrating propulsion design with guidance system, warhead, body, and other components during development of the complete missile.

A New Economic Approach to Rocket Propellant Selection, by Harry R. Biederman and H. M. Kindsvater, Lockheed Missile Systems Division (233-55). A well-received discourse on applying the systems approach to the selection of a liquid oxidizer or a liquid fuel for a rocket weapon. Liquid oxygen and inhibited red fuming nitric acid, in combination with JP-4 fuel, were selected for evaluation. Functional activities such as handling and transporting the propellant were among the factors examined.

Some New Metallurgical Processes of Interest in the Field of High Speed Flight, by Edward C. Bishop, Westinghouse Electric Corp. (234-55). The paper concentrated upon high-temperature-service alloys, a matter of concern to missile technology. Several predictions into the future of practical and industrial metallurgy were made at the conclusion of the reading.

The Satelloid, by Krafft A. Ehricke, Convair (235-55). The reading of this paper attracted considerable interest due, in a large measure, to the zealous enthusiasm of the author for his special project and to an associated awareness of the government's support of space investigations. The theoretical analysis presented is essentially a strong suggestion that low-powered orbiting vehicles (unmanned, then manned) be rocket-propelled up to orbiting altitudes, in the region of 350,000 to 450,000 ft, to fill the "gap" between high-altitude aircraft flight and economical low-altitude satellite orbiting. The coined name "Satelloid" designates use of low-thrust sustainer engines to maintain the orbit. The analysis considered the flight mechanics of the circular and subcircular velocity satelloid at the outer fringes of Earth's technical atmosphere.

Twelve Leading Companies Join Society

FIVE Eastern companies, four from the Midwest and three from Southern California, are included among recent applicants for Corporate Membership in ARS. They are:

American Bosch Arma Corp., Garden City, N. Y.—makers of inertial guidance equipment for missiles; gyros, resolvers, integrators, motors, generators; fire control and navigation systems. Named to the company membership are Charles W. Perelle, president; Clifton T. Foss, vice president and general manager; Edmund D. Gittens, vice president and chief engineer; Fred H. Guterman, assistant vice president of sales; and Leslie E. Neville, director of public relations and advertising.

Atlantic Research Corp., Alexandria, Va.—research and development in solid propellants, jet propulsion, combustion and interior ballistics. Named as members are Lester L. Weil, head, chemistry division; DeWitt O. Myatt, manager of development; John G. Meitner, head of research, chemistry division; and J. Norman Rossen and R. C. Vande Vrede, chemical engineers.

Beech Aircraft Corp., Wichita, Kans.—pioneer aircraft manufacturer, recently entered into the guided missile field. Members are James F. Reagan, manager, missile engineering; A. S. Odevseff, manager, military engineering; D. E. Burleigh, manager, engineering administration; M. J. Gordon, chief of preliminary design and aerodynamics; R. H. Anselm, design engineer.

Bendix Products Division—Missiles, Mishawaka, Ind.—prime contractor for the Navy Bureau of Ordnance's Talos, surface-to-air guided missile powered by a ramjet engine. Individuals named on the Corporate Membership are W. L. Webb, general manager; D. M. Heller, director of engineering; E. P. Halpin, assistant to general manager; F. C. Mock, director, fuel systems engineering; C. M. Shaar, chief project engineer.

Brush Electronics Company, Cleveland, Ohio.—producer of instruments, piezoelectric materials, magnetic heads, acoustic components, acoustic torpedoes, other ordnance products. Magnetic recorders are used for telemetering, missile programming, and data reduction. On the company membership are D. B. Parkinson, general engineering manager; J. H. Harris, general works manager; D. E. Pierce, assistant manager, equipment dept.; T. E. Lynch, vice president and director of ordnance products (Clevite-Brush Development Co.); and W. H. Kliever, vice president and director of instrument development (Clevite-Brush).

Experiment, Inc., Richmond, Va.—research and development of propulsion systems for guided missiles. Members are James W. Mullen II, president, an ARS Fellow Member; Hartwell F. Calcote, vice president, research div.; Frank H. Erdman, vice president; Emery C. Wilkerson, senior scientist, propulsion div.; and Robert L. Wolf, vice president, propulsion div.

Fischer & Porter Co., Hatboro, Pa.—manufacturers of instrumentation and data reduction systems used in development, manufacture, and testing of rockets and jet propulsion devices. Members: Robert K. Stern, vice president, data reduction and automation; Ralph H. Shapcott, manager, flowmeter div.; Joseph F. Wapner, chief engineer, data reduction and automation; Victor P. Head, director of hydraulic research; and Frank P. Houpt, application engineer.

Continental Aviation and Engineering Corp., Detroit, Mich.—manufacturers and developers of thrust producting systems. Members: Carl F. Bachle, vice president, research; Whitney Collins, chief engineer, turbine engineering; John C. Squiers, senior project engineer; turbine engineering; David H. Silvern, senior project engineer, turbine engineering; Seymour A. Genden, project engineer, research div.

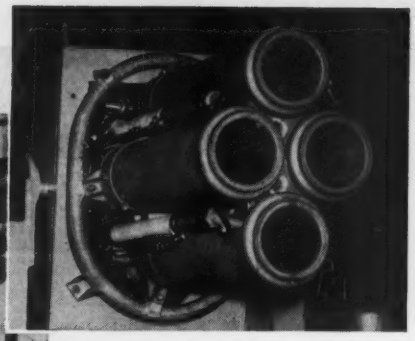
Federal Telecommunication Laboratories, Nutley, N. J.—guidance, control, instrumentation, and navigation systems. Members: Arnold M. Levine, laboratory director, Albert E. Cookson and Robert S. Bailey, associate directors; Martin Press, project engineer; Richard Waer, executive engineer. All are with the Guided Missile Laboratory.

Garrett Corp., AiResearch Mfg. Div., Los Angeles, Calif.—producers of missile accessories. Members: W. R. Ramsaur, vice president, engineering; Leighton S. King, engineering coordinator and chief of preliminary design (AiResearch Mfg. of Phoenix); Charles F. Drexel, project engineer; D. A. Dutton, special projects group; A. J. Phelan, staff assistant.

Hughes Aircraft Co., Culver City, Calif.—prime contractor on the Falcon air-to-air guided missile; research and development on other classified missiles. Members: M. C. Beebe, head, propulsion dept.; T. B. Carvey, assistant head; R. K. Roney, head, systems analysis dept.; L. Stoolman, head, aerodynamics dept.; A. P. Wangsgard, Head, design integration dept.

The Ramo-Wooldridge Corp., Los Angeles Calif.—guided missile research and development. Members: Simon Ramo, executive vice president; M. U. Clauser, director, aeronautics research laboratory; J. C. Fletcher, director of electronics research and development, R. F. Mettler, assistant director of systems integration, and E. R. Toporeck, director of flight test and instrumentation—the latter three with Guided Missile Research Div.

new team impetus...



In the field of fuels research, Olin Mathieson and Reaction Motors are developing new liquid and solid propellants as well as additives to improve current propellants. Reaction Motors and Marquardt Aircraft establish specifications for these new rocket and ramjet fuels and test and evaluate their capabilities for meeting tomorrow's needs.

developing super fuels for supersonic propulsion

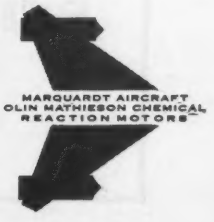
Applying the modern "weapons system" concept to the problems of supersonic propulsion, Olin Mathieson, Reaction Motors, and Marquardt Aircraft are combining their unique skills and experience in the development and production of rockets, ramjets, and special fuels. Coordinated by the OMAR Joint Technical Committee comprised of representatives of the three companies, this applied research program is dedicated to the practical advancement of supersonic aircraft and missile propulsion.

3519

Marquardt Aircraft Company

Olin Mathieson Chemical Corporation

Reaction Motors, Inc.



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New Patents

George F. McLaughlin, *Contributor*

Air starter for gas turbine (2,714,802). Leon R. Wosika, San Diego, Calif., assignor to Solar Aircraft Co.

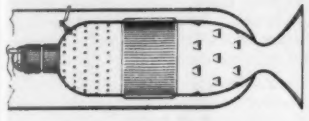
A working gas supplied to a radially directed tubular inlet to the passages between stator and rotor vanes, the discharge side having a diagonally directed auxiliary opening discharge passage.

Fuel metering device for a turbojet engine (2,714,803). Robert N. Abild, New Britain, Conn., assignor to United Aircraft Corp.

Meter with passages connecting a chamber and the exterior of a bellows to the discharge of the compressor, and a passage connecting another chamber and the exterior of a second bellows to the inlet of the compressor.

Pyrophoric liquefied gas lighters (2,714,805). Conrad J. Zellweger, Geneva, Switzerland, assignor to La Nationale S. A.

Valve with a hollow needle enabling the the reservoir of a lighter to be connected to a filling vessel containing liquid gas under pressure.



2,718,757

Aircraft gas turbine and jet (2,718,757). Ward J. Bloomer, Westfield, N. J., and Hyman R. Davis, Jackson Heights, N. Y., assignors to The Lummus Corp.

Combustor for a turbojet engine having a compressed air source and being adapted to discharge heated gases at uniform temperature to a turbine. The combustion chamber has the shape of a curve of revolution. Supplementary air may be passed through secondary air passages to uniformly blend unburned air with the products of combustion.

Rudder-eye coupling for homing bomb (2,715,364). Willard E. Buck, Inyorken, Calif., and Paul Travers, Cambridge, Mass., assignors to the Secretary of War.

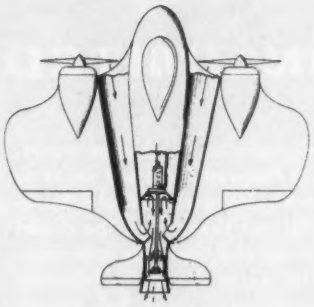
Control system for an aerial bomb in which an eye, sensitive to radiant energy, scans an area about the extended axis of the eye and controls the flight path in accordance with signals from the eye.

Fuel-flow for pural radial inward-flow gas turbines (2,715,814). Richard H. Barr, Ashford, England, assignor of one-half to Centrax Power Units, Ltd.

Power plant with adjustable diffuser vanes, and containing two independently rotatable turbines arranged in series flow association with the respective turbine shaft axes at right angles.

De-icing apparatus for compressors (2,718,350). Neil Burgess, Melrose, Mass., assignor to General Electric Co.

Means for supplying fluid under pressure to hollow portions of vanes extending across the compressor inlet of a gas turbine power plant, to prevent ice accumulation.



2,719,683

Aircraft with fluid propulsion and braking mechanism (2,719,683). Paul Jones, Williamsport, Pa.

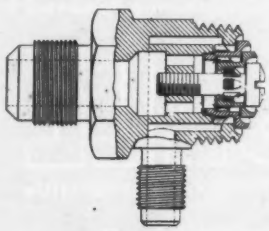
An aircraft with ducts on either side of the fuselage to receive the backwash of a propeller, each curving at its rear end into the fuselage. A rearwardly diverging baffle closes the end of the fuselage to form an air chamber with an opening to permit rearward escape of air. A gate valve permits closing the opening.

Exhaust structure for gas turbine (2,713,990). Leon R. Wosika, San Diego, Calif., assignor to Solar Aircraft Co.

Exhaust duct with a rotor unit supplying exhaust gases to the duct at subambient pressure and appreciable rotational velocity which causes the gases to stratify at the periphery of the duct.

Nonluminous pyrotechnic mixture for a projectile (2,714,061). Raymond H. Heiskell, Compton, Calif.

Igniter for initiating ignition of the burster charge, comprising a peroxide of an alkaline earth metal 60 to 70.7 per cent, antimony sulfide 21.3 to 35 per cent, a bitumen mineral substance 1 to 4 per cent and a friction reducing substance.



2,719,584

Nozzle for rocket motor (2,719,584). Arthur F. Winslow, decreased, late of Schenectady County, N. Y., by Elizabeth L. Winslow, administrix, assignor to the U. S. Army.

Partition within a nozzle, spaced to form a chamber communicating with a hollow arm extending from the body. The chamber terminates in a flared lip at one end of the body, and a longitudinal passage extends through the body. Bushings nest within one another, and a plug within extends into the passage.

Cooling cowl for jet engines (2,717,489). Augustus Hasbrouck, Middletown, Conn.

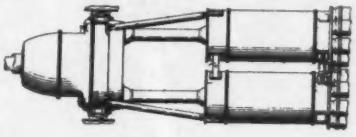
Top and bottom portions of cowling spaced to form a heat exchanging shallow passageway insulated with a spun glass blanket, and having openings to permit air flow. Removable panels have hinged doors on the underside to permit access to the engine.

Compensated means for controlling the supply of liquid fuel to jet-propelled aerial bodies (2,717,490). Charles H. Bottoms, Simonstone, England, assignor to Joseph Lucas, Ltd.

Shuttle valve arranged to differentially vary the buffering action according to the direction of movement of the valve, compensating for the effects of acceleration or deceleration on the throttle.

Jet engine with coaxial fuel and air intake chambers (2,718,116). Charles J. Moses, Oak Hill, W. Va.

Fuel injection comprising a plurality of conduits passing through and terminating rearwardly of an annular wall, and directed into the fuel intake space.



2,718,756

Mounting and supporting structure for aircraft gas turbine power plants having reduction gearing (2,718,756). Chas. J. McDowall, New Augusta, Ind., assignor to General Motors Corp.

Gas turbine engine disposed rearwardly of a power transmission and supported by three struts in triangular array, the strut axes converging toward the engine.

Fuel and [illegible]riable area nozzle regulating apparatus for thermal power plant (2,713,767). Joseph S. Alford, Nahant, and Donald F. Warner, Swampscott, Mass., assignors to General Electric Co.

Exhaust reheat system in which fuel is supplied under pressure at a controlled rate to the combustion chamber. An altitude compensating means reduces the fuel pressure at the upstream side of the control means in accordance with a preselected schedule and in response to variations in the ambient atmospheric pressure.

Rotary jet engine (2,715,391). Norris E. Smith, San Angelo, Tex.

Gas turbine motor (2,718,115). Karl H. Adamek, Pinneberg (Holstein), Germany, assignor to Iconex Handelsgellschaft m.b.H.

Chambered rotor laterally provided with a heating chamber, and coupled with a scavenging blower and a turbine in axial alignment. The rotor is surrounded with a housing tightly enclosing stationary partitions with control openings between the rotor and turbine, and also in communication with the heating chamber.

EDITOR'S NOTE: The patents listed above were selected from recent issues of the Official Gazette of the U. S. Patent Office. Printed copies of patents may be obtained at a cost of 25 cents each, from the Commissioner of Patents, Washington 25, D. C.

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C159	0.024 to 75	100 lbs.—24" cube	44"
D184	1 to 800	6 1-lb. objects	12"
E185	0.01 to 60	300 lbs.—30" cube	72"

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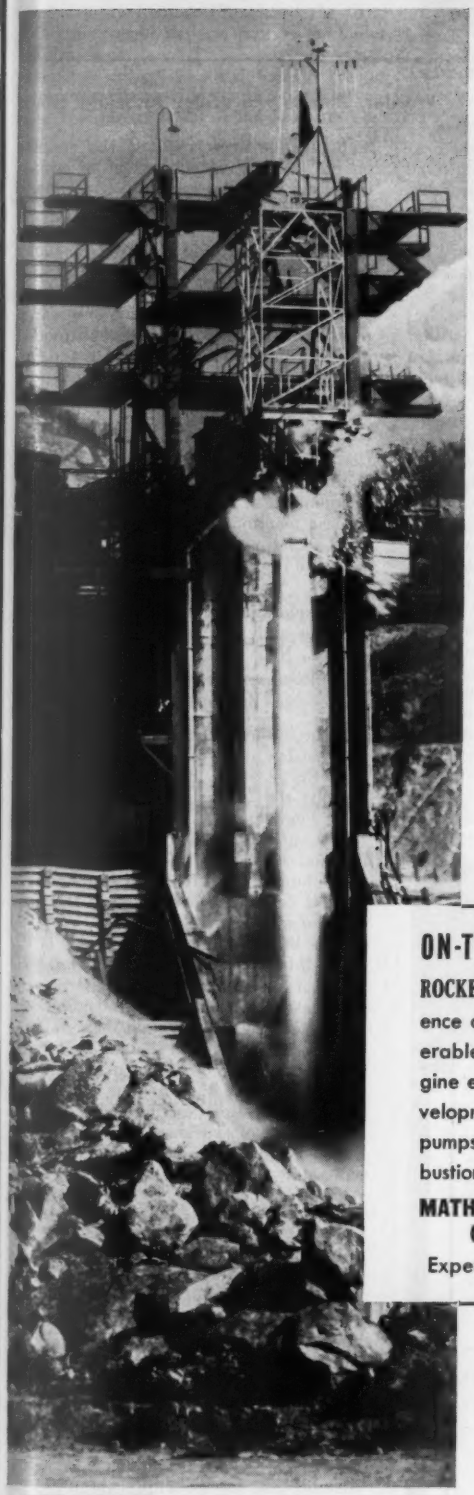

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Book Reviews

C F. Warner, Purdue University, Associate Editor

Progress in Cosmic Ray Physics, Vol. II, edited by J. G. Wilson, Interscience Publishers, Inc. New York, 1954, 322 pp. $8.50.

Reviewed by S. F. SINGER
University of Maryland

In a subject which is developing as rapidly as cosmic rays there is a great need for review articles which chart this progress. Specialists in the field of cosmic rays as well as those who are interested in learning of advances of broad significance welcome; therefore, the publication of review articles such as are contained in the present volume. They are in all cases written by experts in the field. The series is under the capable editorship of J. G. Wilson of the University of Leeds in England. In this second volume of the series he himself has written the review article on the new elementary particles which have been discovered in recent years in the cosmic ray radiation. These subnuclear mesons may yet play an important role in explaining the origin of the forces which bind the nucleus together. Although first discovered in the cosmic radiation, they are now to some extent being produced artificially in cosmotrons and bevatrons. A major review article by Prof. Messel of Sidney, Australia deals with a description of the so-called nucleonic cascade, i.e., the multiplication of particles resulting from the incidence of a single very high energy proton or neutron. In the resultant nuclear disintegrations lower energy protons and neutrons are ejected which go on and create further nucleonic disintegrations. The theory of this cascade process, largely developed by Messel, may be of major significance in explaining the interactions produced by ultra-high energy cosmic rays (of the order of 10^{14} electron volts and higher).

Another excellent review article is given over to photographic emulsions which have played such a large role in recent years in the discovery of new particles in the cosmic rays and in various types of nuclear physics research. Ionizing particles leave tracks in photographic plates which can later be studied and used to determine the properties of the particles and their interactions. This chapter has been prepared by Dr. Voyvodic of Ottawa, Canada. Another review paper deals with the nuclear reactions of the most commonly occurring cosmic ray particles at sea level, the so called mu-mesons. Although their nuclear reactions are rather rare, they shed a great deal of light on the fundamental properties of matter. A chapter discussing their properties from an experimental and theoretical point of view has been prepared by Sard and Crouch of Washington University, St. Louis, Mo. Of some practical interest to high altitude flight may be the chapter on the penetrating component of cosmic radiation in the upper atmosphere, written by E. G. Dymond (now deceased) of Edinburgh. He describes mainly the experimental material collected on penetrating cosmic ray particles at high altitudes.

With the rapid accumulation of research results the field of cosmic rays has divided into two parts, one dealing with the nuclear physics aspects of cosmic rays, and the other with the origin of cosmic rays and their time variations. In future volumes of this series now under consideration both aspects will be discussed. To engineers and physicists dealing with phenomena at high altitudes both the nuclear reactions of cosmic rays and the time variations in intensity are of considerable interest.

The Exploration of the Moon, by R. A. Smith and A. C. Clarke, Harper and Bros., New York, 1955, 112 pp. $2.50.

Reviewed by K. R. STEHLING
Bell Aircraft Co.

So many books have been published in the past few years on the subject of space flight that it is difficult to look at a new one without the feeling that this must have been done before.

The authors of this book recognize this fact and say indeed, that "no achievement of the human mind has been so well documented before the event as has the conquest of space."

This little volume of 112 pages is divided into four parts: 1. The establishment of an earth satellite or group of satellites; 2. The circling of the moon by a robot vehicle and the final descent of a man-made object upon the moon; 3. The first landing upon the moon; 4. The establishment of a lunar colony.

The first section describes the launching and flight of various unmanned and manned orbital vehicles some of which will serve as refueling stations for lunar rockets.

In the succeeding three sections the authors show how a remotely controlled vehicle could be sent to the Moon for advance scouting purposes, then to be followed by the first lunar explorers. The last step is the settlement of the moon by colonists, beginning a great era of colonization which will rival that of the early days of the exploration of the Americas.

The text of the book shows a characteristic sense of idealism and realism. Although the authors contend that man's curiosity and energy will inexorably drive him into the space, they realize that such unromantic matters as finance must be solved. The British and other European authors must perforce gloss over such practical considerations since undoubtedly the United States will foot most of the bill.

The book has as many full-page illustrations as text. The illustrations, while not of "Bonestell" quality, are well drawn

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and greatly help to illuminate the text. The pictures of the colonists on the moon are most interesting. This reviewer was relieved to see scantily dressed young women working with the male colonists in the hydroponic pits. The desirable and necessary presence of women in such enterprises has often not been admitted by English writers.

Summary: A painless description of the first trip to the moon, with a happy ending.

Fundamentals of Transistors, by Leonard Krugman, John F. Rider Publishers, Inc., New York, 1954, 140 pp. $2.70.

Reviewed by D. J. LAMOTHE
Purdue University

This book by Leonard Krugman contains a surprisingly large amount of useful information on transistors in its 140 pages.

Rather detailed mathematical treatment is given to four-terminal network analysis for both passive and active networks. The equivalent transistor circuit is developed and considerable space is devoted to the mathematical treatment of the various transistor connections; namely grounded base, grounded emitter, and grounded collector.

In view of the relatively detailed mathematical developments in many of the chapters, this book would probably be most useful to the practicing engineer who needs a review of active networks and applications in preparation for undertaking a study of the technical literature. The book should also be useful to college students in the junior or senior year who need about a six-week period of study on transistors as part of their electronics curriculum.

Book Notices

Bomb Survival and You, by Fred N. Severud and Anthony F. Merrill, Reinhold Publishing Corp., New York, 1954, 264 pp., $5.95. The authors have attempted to compile all pertinent information and to present it in such a manner that will be of interest to engineers, architects, civil-defense workers, and laymen. Includes such topics as characteristic effects of atom bombs, data from Hiroshima and Nagasaki, control of fire, shelter construction, protection of machinery, and the design of bomb-resistant buildings. A mathematical treatise of blast loadings will be presented in a second volume.

Higher Transcendental Functions, vol. 3, compiled by the staff of the Bateman Manuscript Project at C. I. T., McGraw-Hill Book Co., New York, 1955, 292 pp. $6.50. This volume contains chapters on automorphic functions, Lame and Mathieu functions, spheroidal and ellipsoidal-wave functions, functions occurring in number theory and generating functions.

Numerical Methods, by Andrew D. Booth, Academic Press, New York, 1955, 195 pp., $6.00. The author presents a discussion of the mathematical principles underlying the art of programming for an automatic digital calculator. Such topics as interpolation, numerical differentiation and integration, summation of series, ordinary differential equations, simultaneous linear equations, partial differential equations, nonlinear algebraic equations, approximating functions, Fourier synthesis and analysis, and integral equations are presented.

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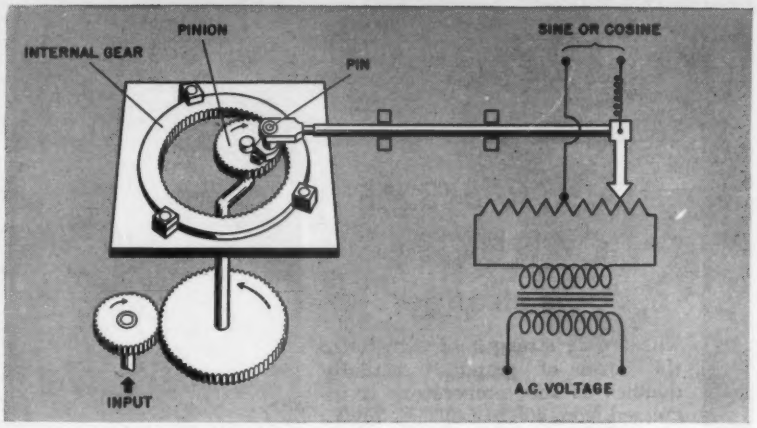

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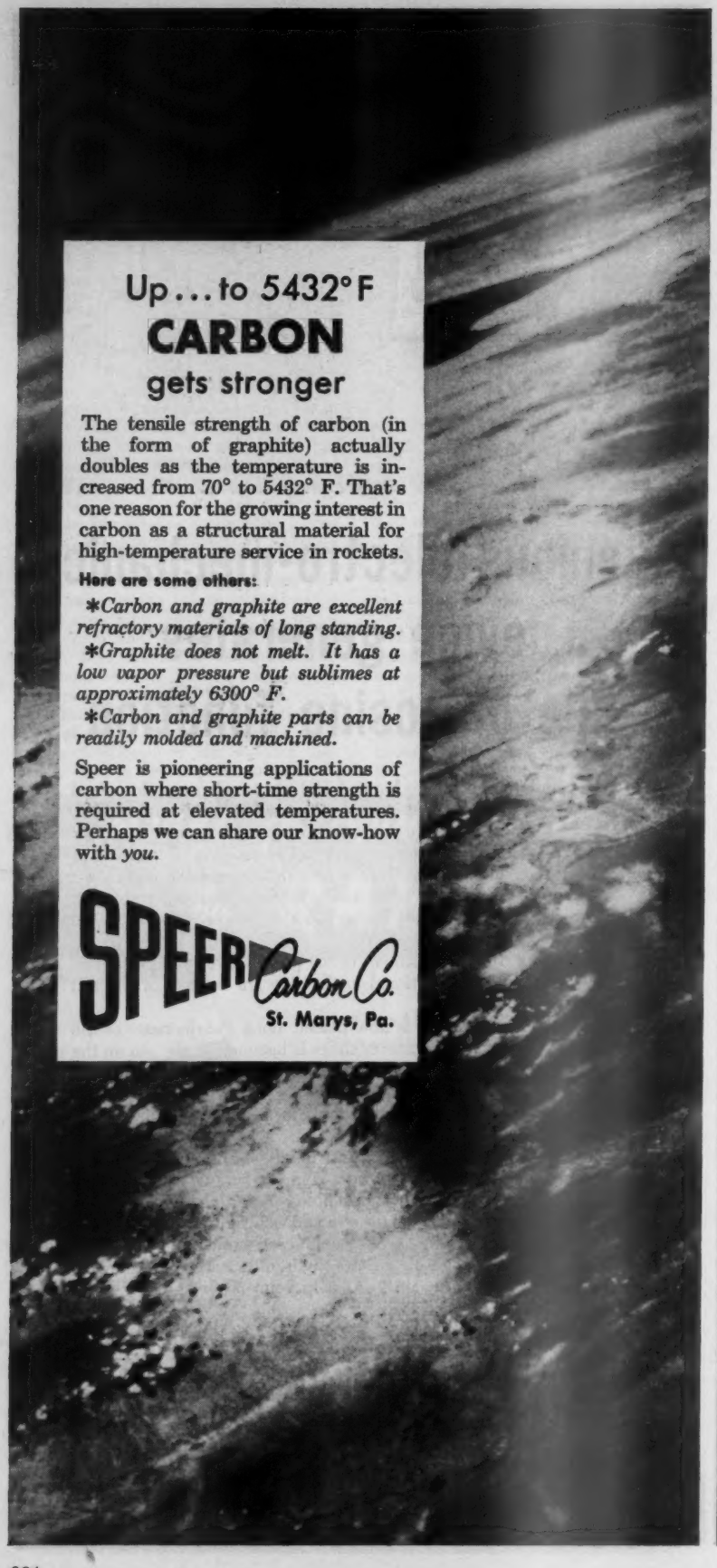
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Space Flight Notes

(*Continued from page 650*)

▸ The Office of Naval Research has in the past sponsored many of the high altitude balloon and rocket-balloon (rockoon) research programs in this country and from ships in the Atlantic Ocean. In 1953, the icebreaker *East Wind* sailed within 442 miles of the North Pole, carrying a group of scientists who launched balloons and rockoons. While much of the cosmic ray and other data which were obtained have not yet been published, the results were encouraging since further research in the Atlantic is under way.

▸ Dr. Jean I. F. King of the Air Force Cambridge Research Center has made mathematical studies of the "weather" on other planets, particularly Mars and Venus. His studies deal mainly with the temperature distributions on these planets, as detected and recorded with sensitive astrophysical instruments. Dr. King shows that Mars should have a relatively quiet atmosphere, while Venus should have violent weather with surface temperatures in the hundreds of degrees and with high winds and dust storms.

Since Mars will approach closer to the earth in 1956 than it has in many years, further detailed studies of its atmosphere can be made.

However, as in all planetary observations which often require high optical and telescopic magnification, the turbulence of the earth's atmosphere is a severe limitation on the image quality obtainable. It would therefore be advantageous if a telescope could be lifted above most of the atmosphere, where the full optical resolving power of the instrument may be utilized. One possibility is that of a manned high altitude balloon, with one or two men in a sealed rotatable gondola, carrying a suitable telescope whose barrel is hermetically sealed as it projects into the gondola. Several such schemes have already been proposed for solar observations.

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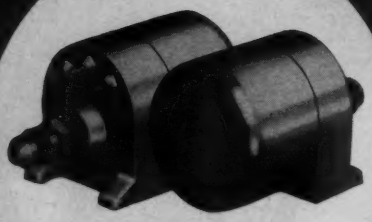

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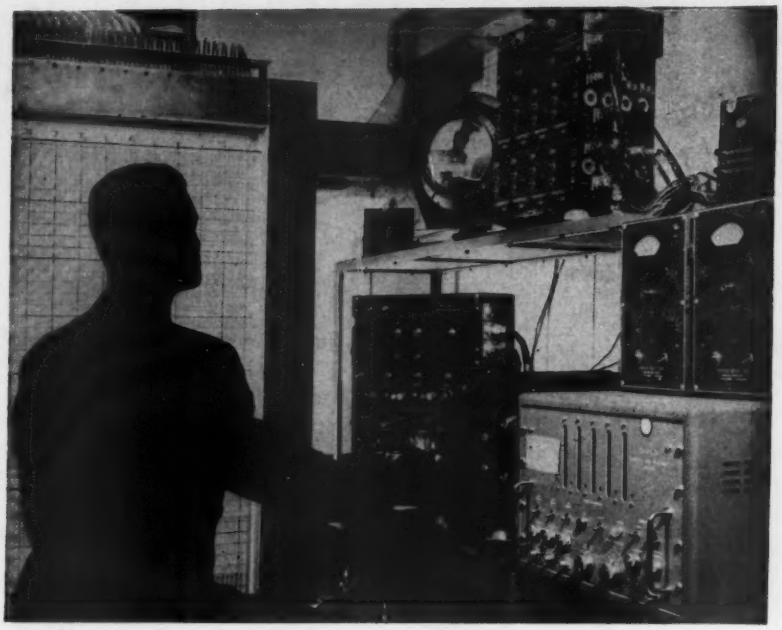

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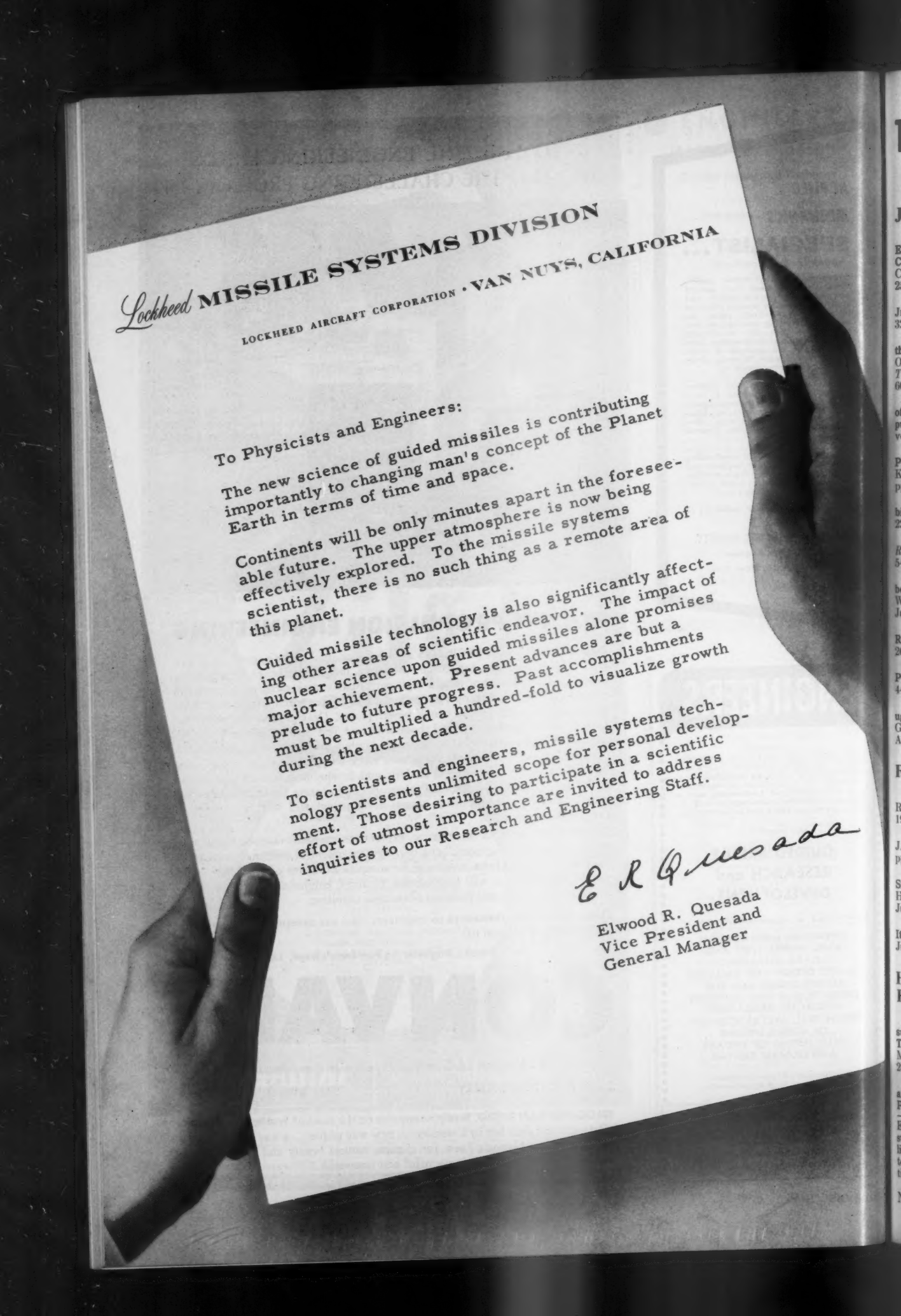

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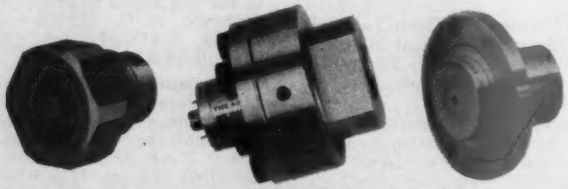

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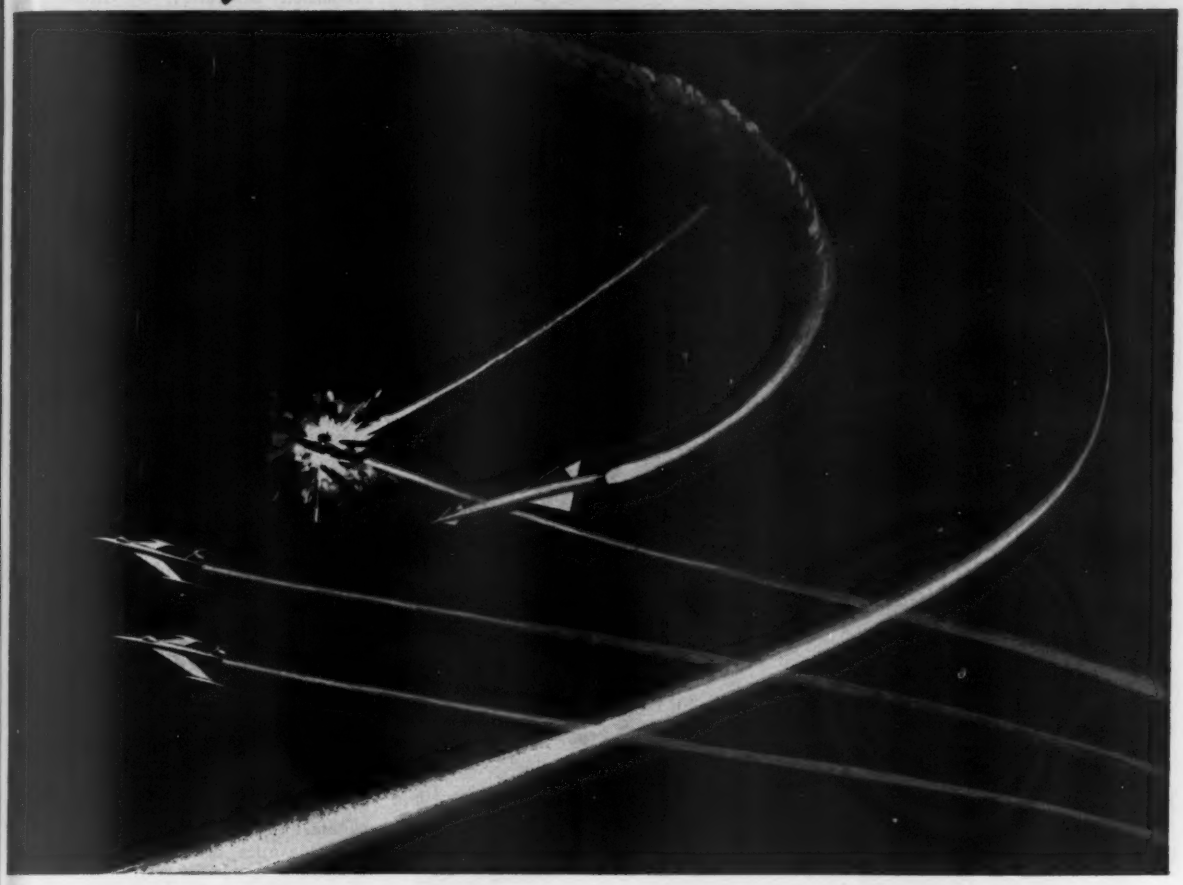

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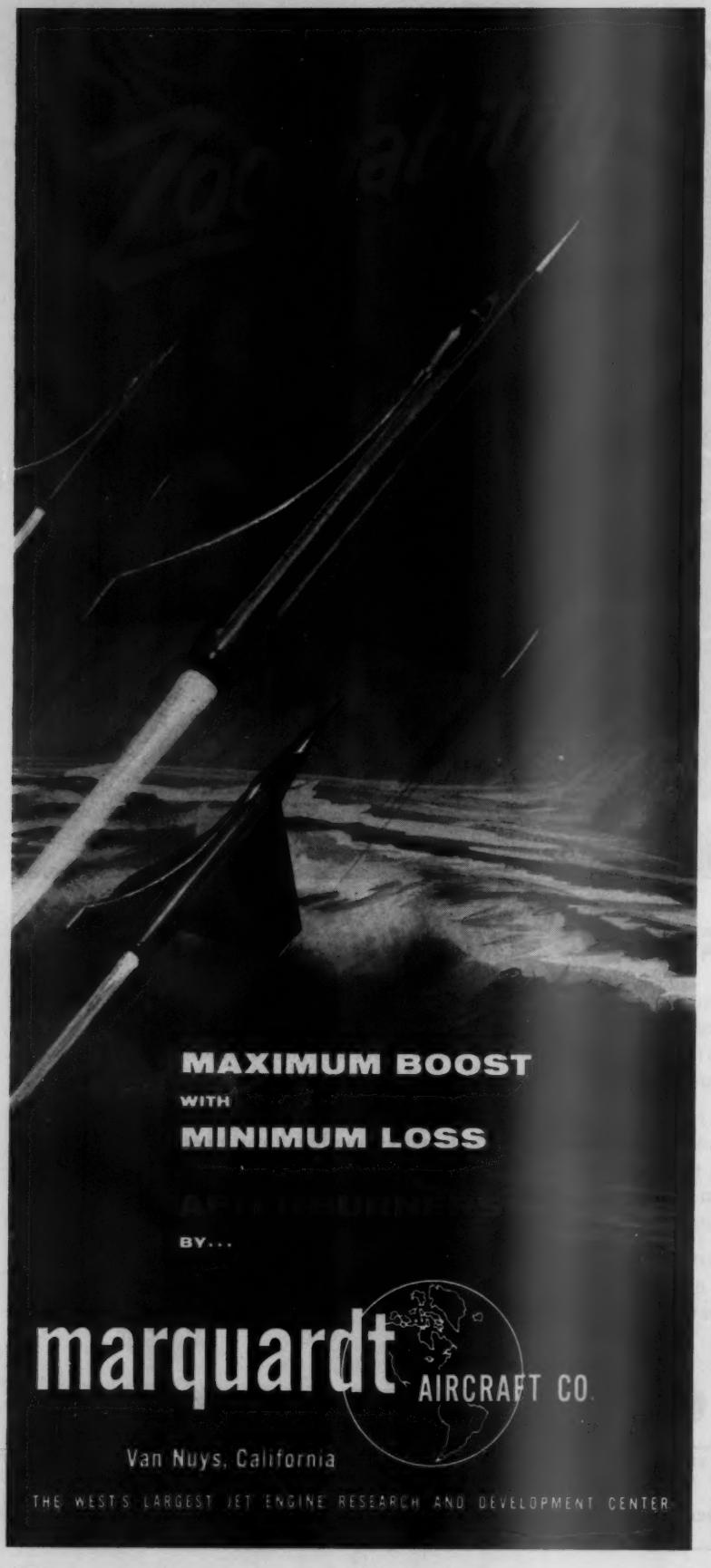

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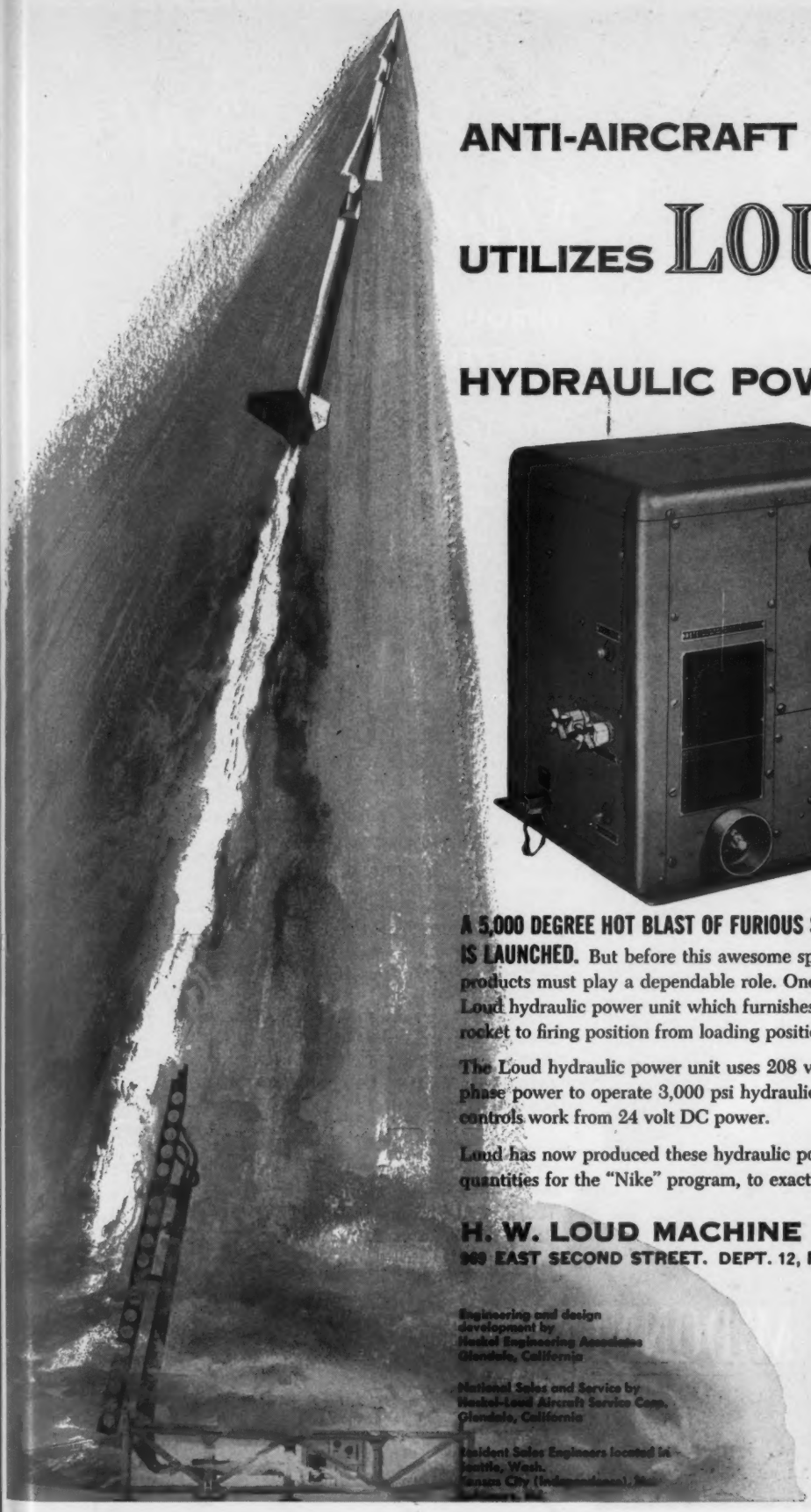

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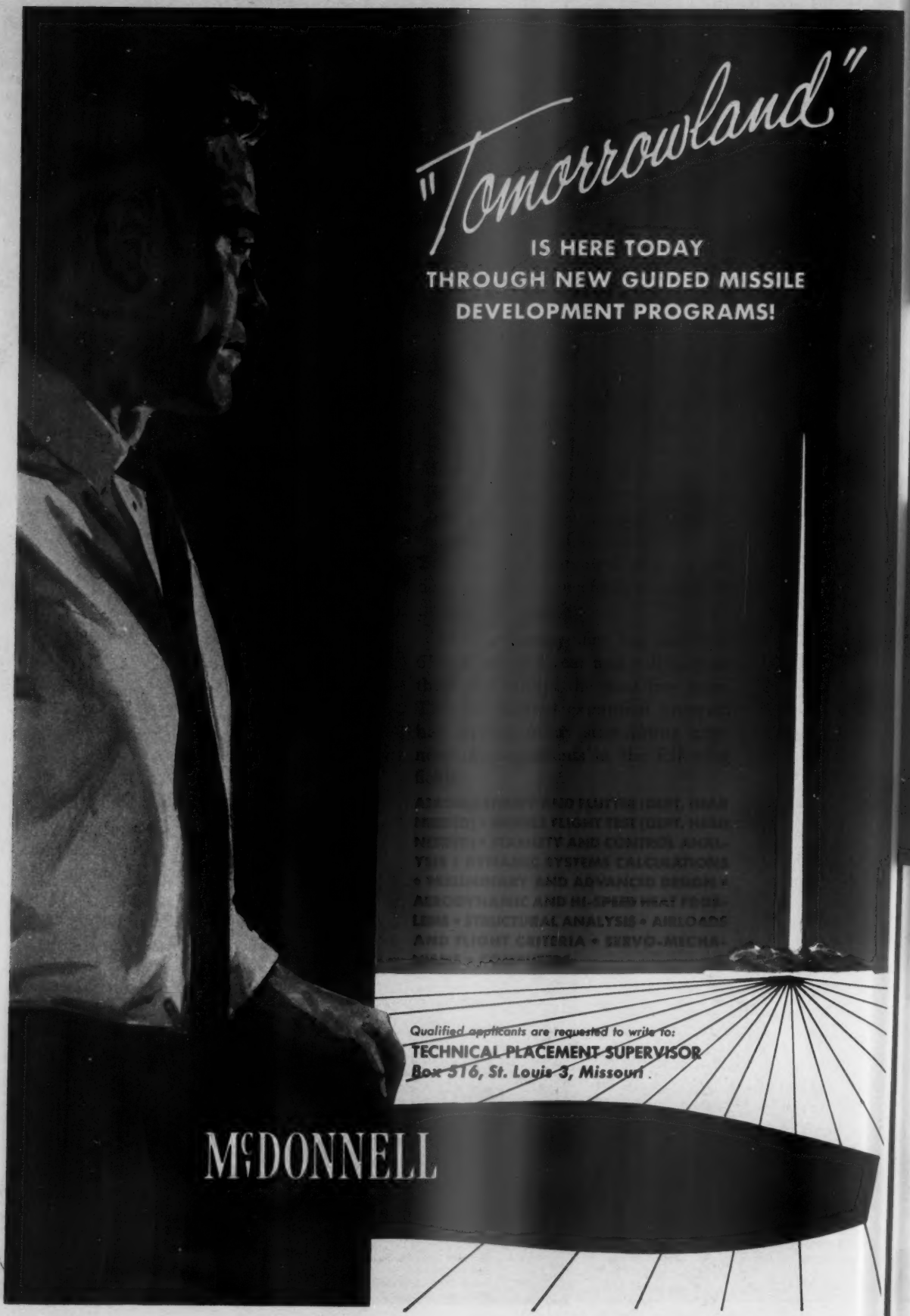
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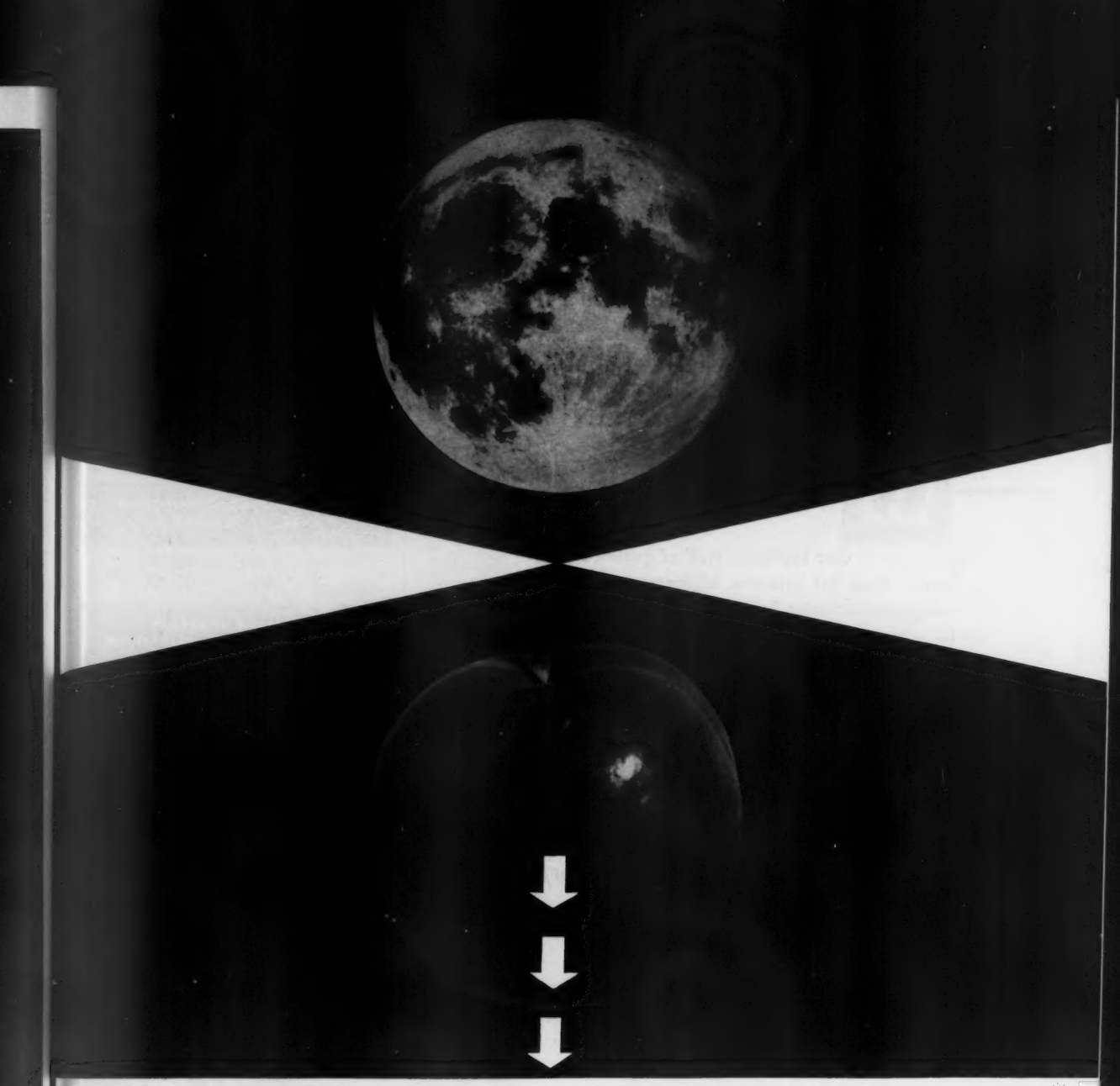

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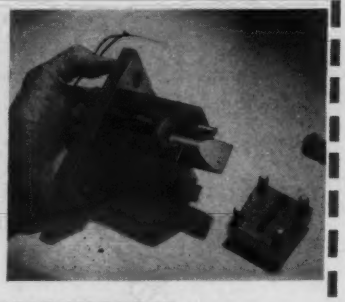

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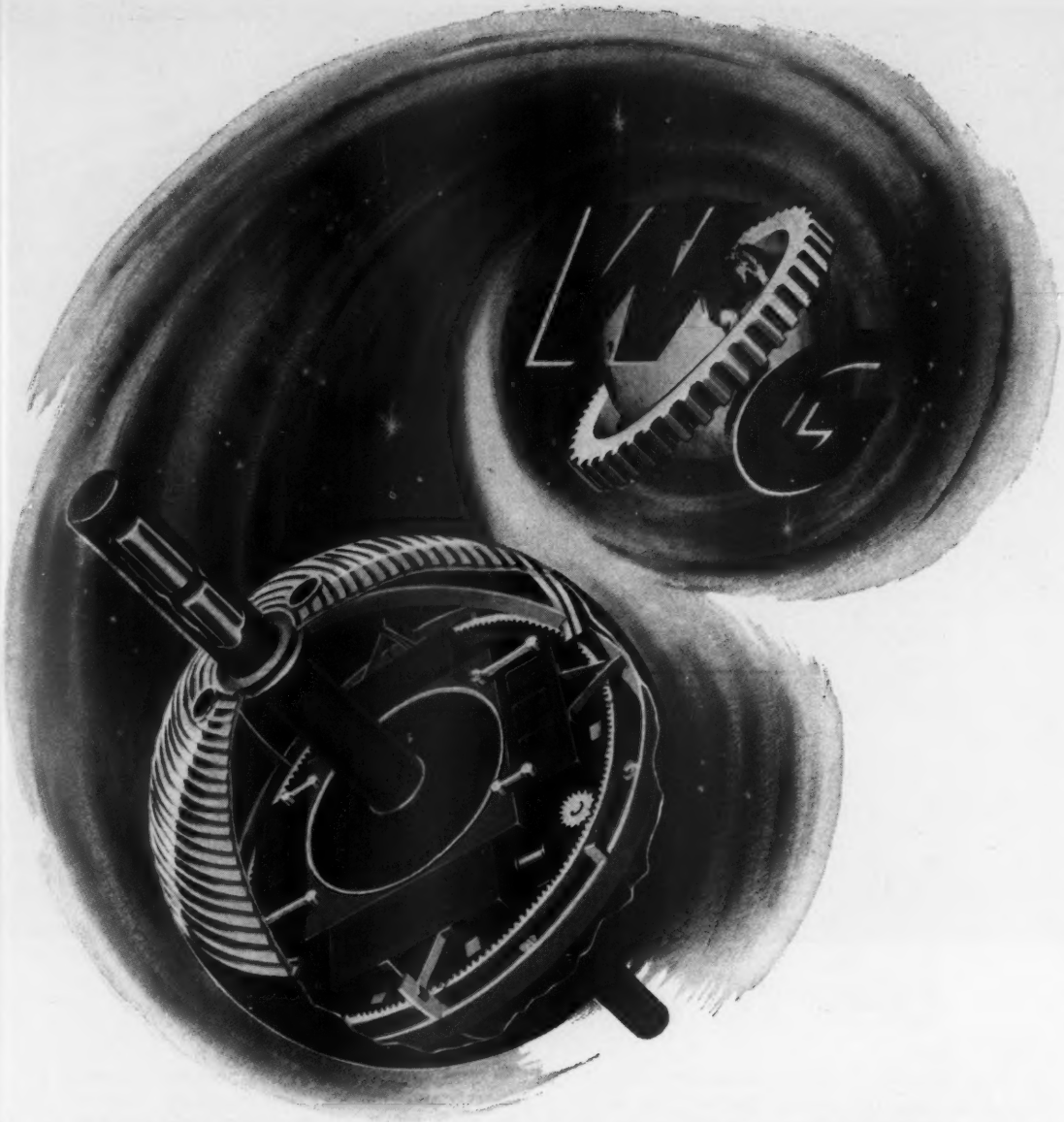

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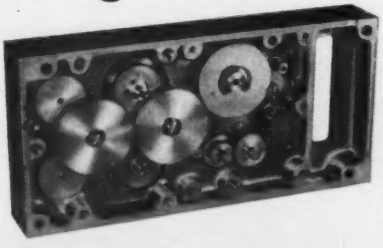

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